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13. ABSTRACT

The prelaunch survival of strategic bombers will continue to be an important problem as long as they are to remain a viable part of the deterrent triad for the United States. Improving enemy technology and changing enemy strategies call for continued analysis of the problem. This study examines the parameters which govern prelaunch survival of strategic bombers. A model is developed to allow computation of total bomber force survival given the values for the necessary parameters. Several basing concepts and other means of improving force survival are analyzed with the aid of the model. Cost effectiveness analysis of the concepts discussed should be accomplished, and the results compared to other possible means of improving survival, e.g., ABM systems, before conclusions are made from the results of this study.

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A FORCE SURVIVAL MODEL FOR ANALYSIS
OF STRATEGIC BOMBER BASING CONCEPTS
IN THE PRELAUNCH SURVIVAL MODE

THESIS

GSM/SM/71-3

Douglas D. Cochard   Robert E. Riggs
Captain   USAF   Captain   USAF

A FORCE SURVIVAL MODEL FOR ANALYSIS

OF STRATEGIC BOMBER BASING CONCEPTS

IN THE PRELAUNCH SURVIVAL MODE

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

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Captain   USAF   Captain   USAF

Graduate Systems Management

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Preface

This study was originally conceived as an analysis
of advanced bomber basing concepts which could be used
to determine whether the B-1 could survive in the SLBM
environment. A desire to write an unclassified paper
limited the problem to simulated threat and reaction
data. Therefore we decided to parameterize the data,
using wide ranges which could include actual data with-
out specific reference to it. This use of phenomenology
allowed the development of a model capable of giving
accurate results when provided with correct input data.

This model was then used in the analyses of basing
concepts and other survival improvement techniques
applicable to strategic bombers. As a result of the
simulated data used, no real answers to the problem
of prelaunch survival are given, but the model remains
valid for operational analysis.

Most other studies in the area of prelaunch survival
are classified, and the models used in their analyses
require computer programs for calculation of results.
Our model is relatively easy to understand, and calcula-
tions can be done by hand or with the aid of a small
calculator. This allows one to get real answers rather
easily to use in a comparison of concepts or for sensi-
tivity analysis of the inputs.

Since cost data was not readily available and time
did not allow the pursuit of cost effectiveness analysis

we feel it is important that further work be done in this area before conclusions on the merits of any of the concepts discussed are reached.

This study was suggested by Mr. L. Donald Seela of the Management Division, Systems Engineering Directorate, Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Major Kenneth E. Brant, also of the Management Division, and Mr. Seela served as our advisors on this project. We wish to express our appreciation for their invaluable advice and encouragement.

We would also like to acknowledge the help we received during early research at the Pentagon and in the Washington, D.C. area. Mr. N. Haller of the office of the Assistant Secretary of Defense for Systems Analysis (OASD/SA), provided direction and insight into the problem of doing this study unclassified. Mr. J.A. Englund, Chief of the Strategic Branch at Analytic Services Incorporated, and his associates, provided us with a background briefing and further explanation of their studies in the area of prelaunch survival of bombers. Messrs. Jerome Bracken and James T. McGill of the Program Analysis Division, Institute for Defense Analyses, explained their approach to the problem of optimizing an SLBM attack on bomber bases. Lt.Col. Vining of the Strategic Bomber Division, AFCSA, briefed us on the scope of the problem and the areas which could be analyzed in an unclassified study.

Lt. Col. R.H. Blinn of the Strategic Studies Division, AFRDQ, is well acquainted with the strategic tanker survival problem and gave us some insight into that area.

.   Any errors contained in this thesis are our sole responsibility. We hope the information presented will prove useful to those who are responsible for decision making in this area, as well as to those who intend to do further studies on the problem or prelaunch survival of strategic bombers.

Douglas D. Cochard   Robert E. Riggs
Captain,   USAF   Captain,   USAF

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Notation

Abbreviations

ABM . . . . . Antiballistic Missile

ASW . . . . . Antisubmarine Warfare

BMEWS . . . . Ballistic Missile Early Warning System

CEP . . . . . Circular Probable Error

FOBS . . . . Fractional Orbital Bombardment System

ICBM . . . . Intercontinental Ballistic Missile

IRBM . . . . Intermediate Range Ballistic Missile

KT . . . . . Kiloton

MIRV . . . . Multiple Independently Targeted Reentry Vehicle

MRV . . . . . Multiple Reentry Vehicle

MT . . . . . Megaton

SAC . . . . . Strategic Air Command

SLBM . . . . Submarine-launched Ballistic Missile

SSKP . . . . Single Shot Kill Probability

Symbols

A . . . . . . Aircraft Survival Matrix

a_{ij} . . . . . Number of Aircraft in Zone i Escaping Threat j

B . . . . . . Bomber Beddown Matrix

b_i . . . . . Number of Airfields in Zone i Used for Bomber Beddown

D . . . . . . Safe-escape Distance

F . . . . . . Force Survival Matrix

f_j . . . . . Bomber Force Surviving Given Threat j

I . . . . . . Aircraft Launch Interval (seconds)

Symbols

L . . . . . . Lethal Radius of Weapon

M . . . . . . Missile Time of Flight

P . . . . . . Probability of Target Kill

R . . . . . . Radius of Probability Circle

S . . . . . . Shock Front Travel Time

T . . . . . . Sum of Critical Survival Times

t_k . . . . . Each Critical Survival Time

W . . . . . . Weapon Yield

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Abstract

The prelaunch survival of strategic bombers will
continue to be an important problem as long as they are
to remain a viable part of the deterrent triad for the
United States. Improving enemy technology and changing
enemy strategies call for continued analysis of the
problem. This study examines the parameters which gov-
ern prelaunch survival of strategic bombers. A model
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Several basing concepts and other means of improving
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Cost effectiveness analysis of the concepts discussed
should be accomplished, and the results compared to
other possible means of improving survival, e.g., ABM
systems, before conclusions are made from the results
of this study.

A FORCE SURVIVAL MODEL FOR ANALYSIS

OF STRATEGIC BOMBER BASING CONCEPTS

IN THE PRELAUNCH SURVIVAL MODE

I. Introduction

> ...the nub of deterrence (is) not
> to have to fight, by virtue of be-
> ing constantly prepared to do so.
>   John F. Loosbrock
>   Editor, Air Force Magazine
>   June, 1971
>   (Ref 40:10)

Virtually every major defense issue has complex diplo-
matic, political, strategic and economic implications
(Ref 53:114). The future of long range strategic bombers
is no exception to this rule. The problems currently
facing the approval and development of an advanced manned
bomber are not the lack of threats from Soviet missiles
or the presence of their air defense system. Its oppo-
sition is political and will be so until the bombers go
into production.

This paper will not attempt to cover all facets of
the B-1 proposal, or even give all the pros and cons of
long range bombers in general. Much is being written on
this topic and it is available for discussion and analysis.
Not so much is available in unclassified form on the
specific topic of survival of the manned bomber. This
then is an attempt to bring together as much information
as is available on this topic in unclassified form, so
that a meaningful analysis of the problem can be made.

Assuming that the triad concept continues to be the strategic deterrent policy of the United States, and that the decision is made to continue with the development and production of an advanced long range bomber, there are certain parameters governing its ability to survive a pre-launch attack, an attack enroute to the enemy's homeland, and penetration of the enemy's air defense screen. This paper will be concerned only with prelaunch survival and the associated variables affecting this survival.

The second chapter will give some background pertinent to the problem. This will be followed by a discussion of the threat and the various strategies available to the enemy. A mathematical model is then developed in the fourth chapter and used in the fifth chapter which is an analysis of various basing alternatives. Total force survival is looked at in each case rather than the survival of individual aircraft.

No anti-ballistic missile (ABM) defense systems will be considered, since the model serves to evaluate whether or not an advanced bomber could survive with improved reaction times and design characteristics.

Other models are available which include more variables, involve more complex calculations, and require computer power for solution. Of course, these models, as well as the one presented in this paper, depend on the accuracy of inputs for valid results.

One computer model originally built to analyze U.S.

bomber survivability against a Soviet SLBM attack is the COG Model developed by the Lambda Corporation. This model employs a generalized Lagrange multiplier approach and considers such factors as missile reliabilities, single-shot kill probabilities, firing rates, geography, salvo sizes, stockpile sizes, warning time, and time-of-flight curves (Ref 17).

A convex programming model for resource allocation with time-dependent objectives was developed by the Institute for Defense Analysis (IDA) to determine the expected number of bombers destroyed in an SLBM attack on bomber bases. Submarines are allocated to possible launch areas to find a targeting pattern that maximizes the number of bombers destroyed. The objective function is non-separable and concave and the constraints are linear (Ref 11). A nonlinear programming text (Ref 10) will aid the reader in understanding this model.

The linear programming approach of Analytic Services Incorporated (ANSER) maximizes the number of aircraft that can take off from their bases during a missile attack from enemy submarines. The mathematical model used is based on the assumption that each side has full knowledge of the total force strength of the other side. This model has been programmed for computer processing (Ref 77).

The model presented in this paper is simple enough for hand calculations and gives real answers, the accuracy of which depends on the inputs. All examples and the

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associated data used to calculate them are hypothetical,
due to the unclassified nature of the paper. They are,
however, as realistic as they can be made using this
information. The model is valid in the ranges of actual
.threats and could be used with inputs of known threat
and reaction data to gain valid information for planning
and operational purposes.

II. Background

>...two legs of a three legged stool
>do not give us the same stability,
>even if greatly strengthened and
>enlarged.
>
>> Robert C. Seamans
>> Secretary of the Air Force
>> Sept. 23, 1970
>> (Ref 63)

During the period following World War II and through-
out most of the 1950's the United States monopoly of nu-
clear weapons and the capability to deliver them inter-
continentally with long range bombers served as the deter-
rent to nuclear war. In the late 1950's it became apparent
that the Soviet Union had the potential for developing a
force of intercontinental ballistic missiles (ICBM) which
could destroy this deterrent. The idea of a "missile gap"
caused the United States to place part of its bombers on
airborne alert and to order a crash missile program. The
gap was closed but the development of the ICBM changed
the strategic balance. During the early 1950's, the
Strategic Air Command (SAC) had a first-strike capability.
As Soviet strategic capabilities grew the United States
developed a survivable command and control capability and
the mission became a second-strike capability, i.e., a
strategic policy of massive retaliation.

First-strike vs. Second-strike

To clarify terms, a "first-strike capability" is the
ability to substantially eliminate the attacked nation's

retaliatory second-strike forces. A "second-strike capability" is the ability to absorb a surprise nuclear attack, and survive with sufficient power to inflict unacceptable damage on the aggressor (Ref 39:205-207).

Kennedy Era

In the period following 1961, the Kennedy Administration found it necessary to be prepared for war at many levels and adopted the policy of flexible (or selective) response. This meant the additional ability to fight a limited conventional war or controlled nuclear war. The Polaris submarine and Minuteman ICBM programs were accelerated and the number of nuclear bombers on 15-minute alert was increased from one-third of the force to one-half (Ref 50:190). These measures provided a clear margin of U.S. nuclear superiority for several years.

Johnson Era

After 1965 the Soviets began to construct their own Polaris-type force, as well as increasing their ICBM deployments and tests of multiple warheads. U.S. strategic superiority was being challenged again. This time it was determined to use restraint. The Johnson Administration reasoned that enemy nuclear superiority would have little military or political significance if U.S. retaliatory capability was not seriously jeopardized, and this became the theory of "assured destruction". This meant that the United States should be capable of destroying a significant

percentage of Soviet population and industry after the worst conceivable Soviet attack on U.S. strategic forces (Ref 53:118-119).

A more complete discussion of how the government determined that the U.S. had sufficient retaliatory power to maintain an assured destruction capability during this period is in the book How Much Is Enough by Alain C. Enthoven and K. Wayne Smith (Ref 20).

Nixon Era

After a review of this strategic doctrine, the Nixon administration view was that:

> ...the overriding purpose of our strategic posture is political and defensive: to deny other countries the ability to impose their will on the United States and its allies under the weight of strategic military superiority. We must insure that all potential aggressors see unacceptable risks in contemplating a nuclear attack, or nuclear blackmail, or acts which could escalate to strategic nuclear war, such as a Soviet conventional attack on Europe (Ref 53:122).

The policy the new administration developed was one of "strategic sufficiency" and was described as the "$1\frac{1}{2}$ war" strategy (as opposed to the "$2\frac{1}{2}$ war" principle of the 1960's). Under Nixon's strategy the U.S. would maintain in peacetime, general purpose forces adequate for simultaneously meeting a major Communist attack in either Europe or Asia, assisting allies against non-Chinese threats in Asia, and contending with a contingency

elsewhere (Ref 53:128-129).

In his statement before the House Armed Services
Committee on the first Five-Year Defense Program of the
Nixon Administration, Secretary of Defense Melvin R. Laird
explains the strategy of "realistic deterrence". The U.S.
foreign policy objectives of lasting peace and freedom
are to be obtained through a national security strategy
of realistic deterrence and a foreign policy strategy
of vigorous negotiation. Strategic military forces help
provide the strength, which together with partnership and
negotiation form the three pillars of U.S. foreign policy.

Soviet Threat

The primary strategic threat to the United States is
the capability of the Soviet Union to deliver long-range
nuclear weapons against targets in the U.S. The Soviet
Union currently has approximately twice the missile payload
capacity of the United States, including ICBM's, IRBM's,
and SLBM's. In addition their strategic threat still
includes a large force of manned bombers. They have
tested a fractional-orbit bombardment system (FOBS),
multiple reentry vehicles (MRV), and new improved ICBM's
and are testing a new bomber (Ref 45:246). In the spring
of 1971 Gen. Bruce K. Holloway, commander in chief of the
Strategic Air Command, said that the Soviet force is made
up of 1400 intercontinental missiles, 650 medium-range
ballistic missiles, 350 sub-launched ballistic missiles,
950 medium- and long-range strategic bombers, and the

largest and most sophisticated antiair and antimissile
defense ever put together anywhere (Ref 32:526).

United States Forces

In contrast to this the U.S. has stabilized its ICBM
force at 1000 Minuteman and 54 Titan missiles, a 41-boat
Polaris/Poseidon submarine fleet, and a reconnaissance
and weapons delivery fleet of 450 bombers. Improvements
to this force in progress are 76 FB-111's now being de-
livered and modification of Minuteman silos for the
Minuteman III intercontinental ballistic missile. Also,
in June of 1970 the USAF awarded a contract for the
engineering development of the B-1, an advanced manned
bomber to be capable of operating from short runways at
austere bases and to have a significantly improved re-
action time (Ref 68:31-33).

Triad Concept

It can be seen then that both the U.S. and the USSR
depend on a "triad" concept of strategic deterrent forces.
This approach consists of land-based missiles, missile
carrying submarines, and long-range bombers. Taken in-
dividually each system has its advantages. The land-
based ICBM's are constantly on alert, reliable, accurate,
and require approximately 30 minutes to reach their
targets. The missile carrying submarines offer a
difficult targeting problem to the Soviets, and their
SLBM's have a very short flight time. The manned bomber

can be launched and then recalled or rerouted; it can be on airborne alert; it can strike a series of targets with varied weapons; and it can be reused.

Taken together these three systems offer the reliability inherent in multiple independent approaches, as well as complicating the enemy's defensive problems and offensive strategies. The concept is flexible enough to wage nuclear wars below the level of general war (Ref 59). With diversification of strategic forces there is not complete reliance on any single system which could be negated by an enemy technological breakthrough. If one system were to be relied upon, the consequences of technological surprise could be sudden defeat (Ref 43).

Another purpose of the diversified force is to make it impossible for the enemy to launch an attack against all three elements simultaneously without providing sufficient detection and warning time to enable one or more of the remaining elements of the triad to retaliate. For example, if they attempt to attack simultaneously with ICBM's and SLBM's, the ICBM's would have to be launched approximately fifteen minutes ahead of the SLBM's. This warning time allows the strategic bomber force on alert to launch and escape destruction. If bomber bases were to be a prime target for surprise attack by SLBM's, then they would have to delay launching their ICBM's to avoid them being detected before the SLBM's. This case allows adequate time for the decision to be made to

launch the U.S. ICBM force (Ref 46).

In a speech in Abilene on 7 May 1971 the Air Force
Chief of Staff, General John D. Ryan, said:

> In order to preserve the sufficiency of
> our strategic forces, it is vital that we
> preserve the special advantages of the
> strategic Triad...If the great flexi-
> bility of the manned bomber is to be
> available in the future, the B-1 will
> have to be available in the 1980's
> to do what the B-52 has done in the
> 1960's and 70's (Ref 46).

If the manned bomber is to remain a viable part
of the triad it must be able to survive a surprise
attack from the most severe enemy threat, survive enroute,
and survive penetration of the defenses of the enemy's
homeland. Each of these three modes of survival present
different problems. One feature of all the problems though
is that they become increasingly difficult to counter as
technology improves.

Soviet Technology

Dr. John S. Foster, Jr., Director of Defense Research
and Engineering and the government's ranking weapons
technologist, said in an interview with _Air Force Magazine_
that it can now be shown "with high confidence" that the
Soviet Union's military technology effort is outstripping
that of the United States, probably between 40 and
50% (Ref 67:28). Since 1968 the Soviet research and
development budget has increased at 10% to 13% per year,
while that of the U.S. has remained essentially constant.

It is felt that if this rate continues the Soviets could gain the technological lead by the mid-1970's. As a consequence, technological surprise could result in unexpected threats to strategic force survivability (Ref 36:56).

There are those who say that all missiles should be moved out to sea. In an interview in U.S. News and World Report, Dr. Foster said:

> I do not agree, and for two reasons: First, from time to time, we find potential weaknesses in each of our weapons systems. We have found them in each of our three strategic systems --the land based missile, the sea-based missile and the long-range bomber. For a period of months or even a year or two, one system or another in the past has had faults which would have made them vulnerable to an enemy had he been aware of them. We cannot guarantee this will not continue to occur again and again in the future.
>
> Second, the Polaris submarine could have an Achilles heel, so to speak. While they are currently judged to be the least vulnerable of our strategic forces --because they are in a sense hidden in the vastness of the oceans--we can't be sure we know everything about what the Soviets are doing to counter this invulnerability (Ref 21:29).

In line with these thoughts, it should be noted that if a breakthrough is made by the Soviets in ABM technology, this would affect all forms of ballistic missiles whether they are fired from silos, submarines, mobile ground launchers, or aircraft.

These technological considerations and the switch

from U.S. nuclear superiority to a policy of "realistic

deterrence" over the past years has many people in the

Defense Department worried. The primary reason for the

current U.S. trend is economics. In the three years since

.1968 the United States has reduced its technological

efforts in the defense and space sector by approximately

$3 billion. This coupled with the level of competence

which the public and the Congress attach to the

management of weapons development during this period of

reduced and reluctant funding of defense programs

constitute problems of immense importance which must

be resolved (Ref 67:31-32).

Secretary of the Air Force Robert C. Seamans at a

National Security Seminar in 1970 said:

> ...I feel strongly that the major need of
> the Air Force today is a new strategic
> bomber to replace the venerable B-52
> (Ref 64).

B-1

In January of this year Maj. Gen. Paul N. Bacalis,

DCS/ Plans of Strategic Air Command, described the B-1

to a meeting of the American Ordnance Association in

Orlando:

> In 1980 the newest B-52 will be 18
> years old. Even with a continuation of
> the extensive B-52 modification pro-
> gram, the endurance of its basic
> airframe cannot be prolonged indefinitely.
> With Soviet defenses increasing in both
> sophistication and numbers, the time
> that bombers require at very low alti-
> tude will eventually exceed the range
> possibilities of both the B-52 and FB-111.

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> In addition, automated offensive and
> defensive systems will be needed to
> prevent increasingly complex tasks
> from exceeding the abilities of the
> operator, and quicker reaction will be
> necessary to counter the growing Soviet
> SLBM threat (Ref 6).

As of 1 June 1970, according to Secretary of Defense Laird, the U.S. has 4200 nuclear weapons in its strategic force. Of these weapons 15% are carried by the Polaris SLBM force, 25% by the ICBM force, and the remaining 60% by bombers. If the ICBM and bomber forces are permitted to become vulnerable to surprise attack, the U.S. would be relying on the submarines at sea and on alert carrying less than 15% of these strategic weapons for retaliation (Ref 37).

The B-1 is currently scheduled to be the replacement for the B-52, which went into production in the 1950's with the technology of that period. The B-52 has been modified many times and is reaching the point where its safety and serviceability beyond 1980 is questionable (Ref 59). Since the time span to develop a new bomber and get it operational is 8 to 10 years, the B-1 program will have to continue at its present pace or be accelerated if it is to be usable in the 1980's.

As the first attack in a long-range formal program by the Members of Congress for Peace through Law (MCPL), the "B-1 Report", prepared by Senator George S. McGovern (D-S.D.) and Representative John F. Seiberling (D-Ohio), was released on 4 May 1971. Replies to this report are

just beginning to surface. Regardless of the merits of
the report, which is said to contain a great number of
careless statements of fact, it is evident that the B-1
will face a fight each year when the Congress considers
the funding requests (Ref 76:14-16 and 73:20-21).

Objective

If an advanced, long range manned bomber, such as
the B-1, is to be built, what will be the necessary
requirements to insure its survival? The prelaunch
survival of this weapons system will be the topic for
analysis in this paper. The intent will not be to
justify the requirement for a manned bomber, but rather
to examine the parameters affecting its survival in the
prelaunch mode of operations.

III. The Threat

'Tis best to weigh
The enemy more mighty than he seems.
Shakespeare:
King Henry V, 1598
(Ref 29)

The threat referred to throughout this chapter and subsequently throughout the entire report is the threat to prelaunch survival of manned bombers. Enroute and penetration problems which the safe-escape bombers will ultimately encounter are not within the scope of this paper.

With respect to warning time, the most severe current threat to the prelaunch survival of manned bombers is the sea-launched ballistic missile (SLBM). The ballistic missile early warning system (BMEWS) can provide 15 to 20 minutes of warning time for an ICBM attack. When the SLBM is considered, this time is drastically reduced. Depending on the distance at sea from which a missile is fired, possible warning time dwindles to from 4 to 8 minutes (Ref 41:252). These warning times could be reduced even more as advanced technology allows the development of depressed trajectory SLBM's yielding shorter flight times.

To aid in countering this reduced warning time, the U.S. Air Force has recently developed a seven site radar network to detect underwater launchings from the coastal waters around the United States. This system uses a

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special computer at each site to compute the point and time of launch and predict the exact point and time of impact (Ref 65:3).

Whether or not long range bombers would be subjected to this worst case (SLBM attack) depends on the strategy the enemy chooses. There are, of course, threats from many countries, but the Soviet forces so overshadow those of all other potentially hostile nations that the Soviet Union can logically be used as the one nation against which U.S. capabilities must be measured (Ref 22).

Several possible strategies are summarized below, but it should be noted that this is not a totally exhaustive listing of enemy alternatives.

Simultaneous Launch

One attacking strategy to be considered is the case of a simultaneous launching of SLBM and ICBM weapons. In this case, if the enemy SLBM's are launched against U.S. missile sites, all of the U.S. bomber force could be safely airborne before the arrival of the first enemy ICBM. Should these SLBM's be targeted against the bomber bases, most U.S. missiles could be safely launched after some hits have been received (Ref 60).

Most authorities assume that the Soviets do not expect the United States to launch its missiles on warning, but rather to absorb a first strike. However, the enemy knows that there is no reason for the United States to hold back its bomber force. The bombers can be launched on warning

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and then later recalled if the warning proved to be false (Ref 52:33).

In the cases mentioned above the arrival times of the SLBM would be somewhere in the neighborhood of 4 to .8 minutes after detection, depending upon submarine location and target area. While BMEWS provides 15 to 20 minutes of warning from an ICBM attack, the detection of SLBM's, given a simultaneous launch, would provide additional time for all untargeted forces to react. This time could be as great as perhaps 26 to 30 minutes.

Obviously, the two cases above could be mixed to some degree so that the most favorable targets in the eyes of the enemy would be targeted by the SLBM weapons. In any event, remaining forces would be subject to the conditions above.

Simultaneous Arrival of SLBM-ICBM

In the case of simultaneous arrival of SLBM's and ICBM's, BMEWS would detect the ICBM attack approximately 15 to 20 minutes in advance of weapon arrival. This would be before the actual launch of the SLBM's and thus all forces would have approximately 15 to 20 minutes to react. This would allow the United States to safely launch most manned bombers, depending on bomber beddown and alert status, and fire as many missiles as desired.

This alternative does not seem to be advantageous to the enemy since it gives more warning time to the United States' forces than other alternatives.

Simultaneous Detection

Simultaneous detection implies some timing between that of simultaneous launch and simultaneous arrival. In order for the enemy to initiate such an attack they would have to be familiar with the various warning systems in the United States. It may be assumed that this information could be in the hands of the enemy, and they should be able to approximate the required intervals to induce simultaneous detection.

In this case one can simply look at the shortest possible warning time, i.e., that of the SLBM attack, and insure that the bomber beddown is such that an adequate force level of bombers will reach the safe escape distance prior to the detonation of the earliest arriving warheads.

Note that the incoming ICBM force will arrive within a shorter interval after SLBM impact than in the case of simultaneous launch. Thus, from the standpoint of warning and reaction times, simultaneous detection appears to be a more favorable strategy for the enemy to use.

A decision model can be used to determine the attack strategy which appears to be the most advantageous to the enemy. When a payoff matrix is used, its values are frequently difficult to determine with any great accuracy. In particular, the problem presented here might require a determination of any or all of the following: target value; bomber versus missile value; safe escape payload in numbers and sizes of warheads, and the number of

targets which would be destroyed by this payload.

One means of establishing values for the payoff matrix is to use relative values based on some known criteria. For this example it is possible to use time as a baseline. The time available for launch and escape of U.S. missiles and bombers after detection of an enemy ICBM/SLBM attack will give the relative values needed. The theory is that the shorter the warning time, the higher the payoff to the attacker. This approach might yield values similar to those used in the following example:

ICBM time of flight .... 25 min.

Detection time .... 3 min.

Reaction time available ... 22 min.

SLBM time of flight .... 11 min.

Detection time .... 1 min.

Reaction time available ... 10 min.

The payoff matrix is shown in Table I.

Table I

Payoff Matrix

		TARGETING			
		SLBM vs. Bombers b_1	ICBM vs. Missiles b_2	SLBM vs. Missiles b_3	ICBM vs. Bombers b_4
ATTACKER STRATEGIES	Simultaneous Launch a_1	10	24	10	24
	Simultaneous Arrival a_2	22	22	22	22
	Simultaneous Detection a_3	10	22	10	22

Since it is desirable for the attacker to attempt
to minimize the amount of warning time available to the
attacked nation, strategy a_3, simultaneous detection,
dominates the other strategies and thus would be the
most advantageous to him.

If certain values in the payoff matrix are changed
(for purposes of illustration) so that strategy a_3 is
no longer dominant in all cases, another decision rule
must be used to determine the best strategy. Suppose
the value for simultaneous launch and SLBM vs. missile
bases (a_1b_3) is changed to 9 minutes. Then note that
strategy a_3 still dominates a_2, but not a_1. If the
attacker is assumed to be conservative, or even pessi-
mistic, the minimax criteria can be used (Ref 48:380).
This implies that the attacker wishes to minimize the
maximum warning time available to the nation under
attack. The minimax criteria again yields selection
of strategy a_3, simultaneous detection.

Note that strategy a_2, simultaneous arrival, was
dominated in both cases, and therefore ruled out as an
optimal strategy with respect to the warning time
criteria used in the example payoff matrix. If some
other criteria were to be used as a baseline for relative
values, it is certainly possible that the results might
indicate some other strategy to be the optimal one.

In the example just given, the attacked nation had
no choice of action, and his available reaction time to

escape the attack was shown as a state of nature or
an assumed certainty (Ref 48:49). If some options were
available to the nation under attack, as well as the
attacker, and each side's action is assumed to be
strictly competitive, i.e., one's gain is the other's
loss, a two-person zero-sum game could be used to
determine the most likely strategy for each to choose.
In this case the decision maker assumes that his oppo-
nent will select his best counter course of action.
Using this pessimistic assumption, the decision maker
selects the safest course of action (Ref 58:501-506).
For sample applications of game theory to military
decision making refer to references 57 and 28.

Increased technology in detection systems could
eventually force the interval between ICBM launch and
detection to be comparable to the SLBM launch/detection
interval, and thus the simultaneous launch strategy
would become equivalent to that of simultaneous detection.

SLBM Pindown

A situation could possibly exist whereby high
altitude nuclear detonations from SLBM's could force
the postponement of U.S. ICBM firing sufficiently to
allow for the arrival of enemy ICBM's. The much larger
and more crippling warheads could then perhaps destroy
the U.S. retaliatory capability via the ICBM. This
strategy would require the enemy to commit most of
its offensive forces against U.S. ICBM sites, thus

freeing bomber bases from attack and allowing the U.S.
bomber force to escape.

This attack pattern might be based on the opinion
of enemy strategists that their air defense forces could
destroy attacking manned bombers enroute or during
penetration.

It is questionable whether the enemy would have
enough missiles to pin down U.S. forces. Also, the
effectiveness of enemy air defense forces against low
altitude bomber penetration is unproven.

Other Enemy Capabilities

One current capability of the Soviet Union is the
multiple reentry vehicle (MRV). This is simply the case
whereby one incoming missile deploys several warheads in
a shotgun type pattern to increase the range of target
destruction and allow for the use of decoys to confuse
ABM defenses.

The multiple independently targeted reentry vehicle
(MIRV), a more advanced system already tested by the
Soviets, is a payload for a single missile and consists
of a number of warheads or penetration aids that can be
individually assigned to designated targets or spaced
in arrival time to the same target (Ref 23). Both of
these delivery concepts (MRV and MIRV) will be considered
in Chapter V.

An even further development in missile capabilities
is the fractional orbital bombardment system (FOBS).

This threat may involve the launching of Soviet missiles in a southerly direction instead of the much shorter northern route. The weapon could be placed in orbit and then de-orbited at the proper time to impact a target area in the United States. An advantage of this strategy to the enemy is that the U.S. does not have a large radar detection system such as BMEWS pointed to the south. Also, if the U.S. did detect the orbiting missile, it could not be immediately ascertained whether or not it was a warhead to be deployed against the U.S. until the de-orbit sequence began. This would allow an extremely short warning time.

Finally, advancements in the space programs could eventually lead to an orbiting launch pad capable of attacking any target on earth with very large payloads and very short warning times.

Value Targeting

It seems highly probable that several high value targets would be included in the target areas of the first wave of incoming enemy weapons. These areas include such places as Washington, D.C., SAC Headquarters, North American Air Defense Command (NORAD) Headquarters, BMEWS and other large radar installations, and other similar targets the destruction of which could severely hamper the U.S. capability to conduct a war of any magnitude.

While this strategy does not affect the initial

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warning times available, it could surely hamper successive
operations. This further points out the need to have
retaliatory forces airborne before an initial attack
is absorbed.

Future Developments

Future improvements in surveillance techniques,
such as satellite detection systems, improvements in
submarine detection and ASW techniques, improved reaction
capabilities of men and machines, and the development of
an ABM system could improve the survival conditions for
the defending nation. Improved missile trajectories,
payloads, ranges, guidance systems, and deployment could
enhance the attacker's position.

Whatever the case, the most severe current and
projected threat to the prelaunch survival of manned
bombers, with respect to warning time, is the submarine
launched ballistic missile. For purposes of this paper
a range of possible SLBM threats has been chosen which
should encompass current capabilities, as well as those
extremely severe threats which are beyond the state of
the art at this time.

While missile time of flight versus range data does
not represent an exact linear relationship, it approxi-
mates a linear function in the ranges pertinent to this
study. Linearity is not a requirement of the model to
be developed, but it was assumed for simplicity in this
paper.

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Threat Data

The purpose for using the five threats shown in Figure 1 is to allow the reader to select any particular threat he may feel approximates one he is concerned with. If actual threat data is available, it may be used with a resulting increase in accuracy.

For analysis of the various threats in Chapters IV and V, it is convenient to construct six 200 nautical mile contour intervals on the continental United States from the coastline inwards. The result is shown in Figure 2.

Similarly, it is convenient to choose 100 nautical miles from the U.S. coastline as the enemy submarine location for missile launches. Given this deployment of submarines, every 200 nautical mile increment from the submarines is precisely the center of succeeding target zones. This allows one to calculate an average time of flight of an SLBM to all bases in any particular zone. The most interior point of the U.S. is 1100 nautical miles from the coastline and thus 1200 nautical miles from a submarine.

The maximum error which could be introduced by using these discrete zones is from 35 to 50 seconds, depending on the threat used. However, the distribution of bases about the mean distance for each zone tends to cancel this type error when determining total force survival. For bomber survival on individual bases, calculations can be made using the exact distance from the nearest

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Figure 1. Five Hypothetical SLBM Threats

Note: Threat I (top line) is least severe, i.e., longest time of flight.
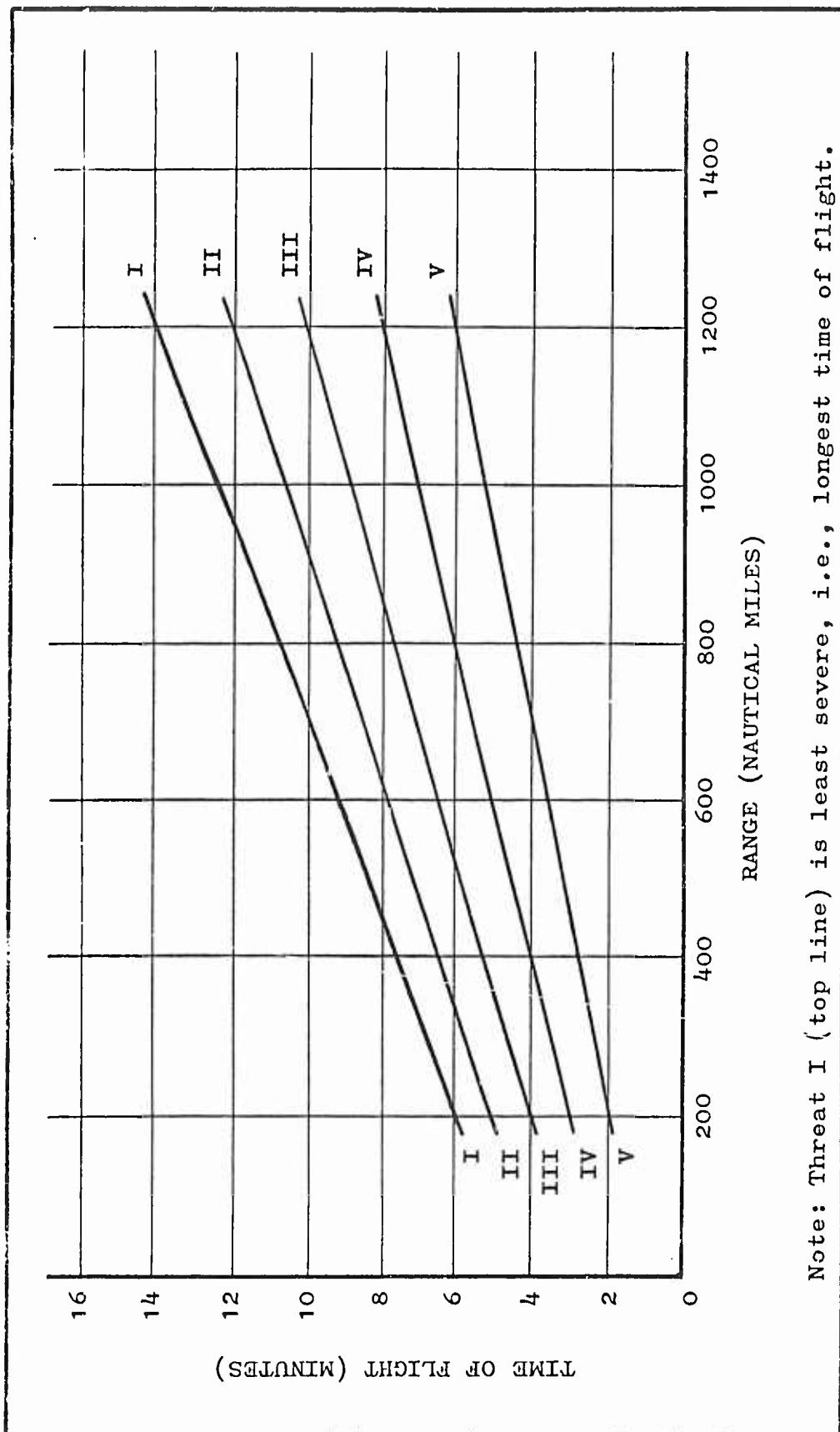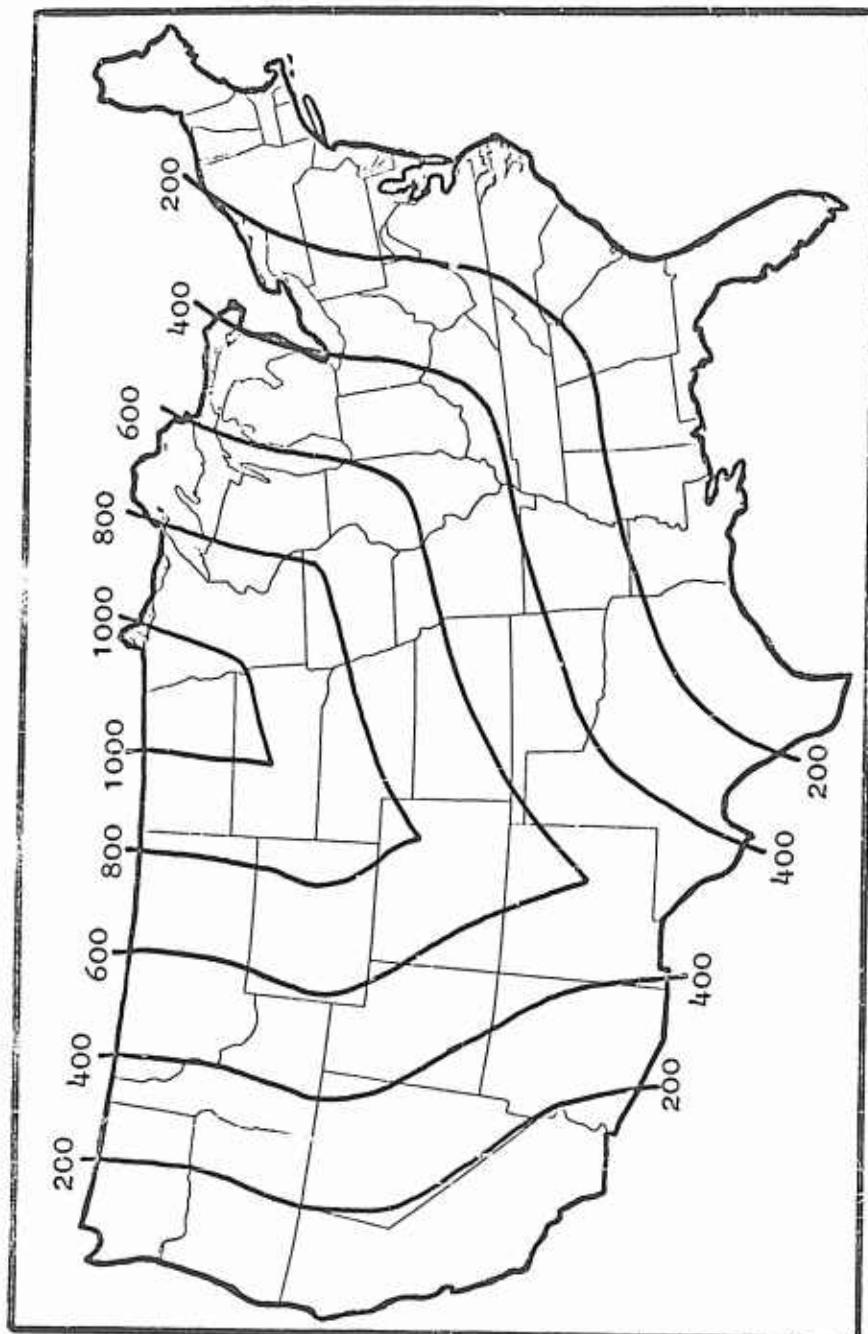
Figure 2. 200 Nautical Mile Contours from Coastlines

coastline, since the threat data is continuous. This
is explained in greater detail with the development of
the model in the next chapter.

Table II summarizes time of flight data for the
five threats to the midpoints of the six zones, given
an SLBM launch position 100 nautical miles from the U.S.
coastline. These values are extracted from Figure 1 at
200 nautical mile increments. This data will be used
extensively in the example problems and in the basing
analysis. Table III summarizes the various threats and
strategies discussed in this chapter.

Table II

Threat vs. Time of Flight Data

Threat	Missile Time of Flight in Minutes					
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
I	6.00	7.50	9.25	10.75	12.50	14.00
II	5.00	6.50	7.75	9.25	10.50	12.00
III	4.00	5.25	6.50	7.75	8.75	10.00
IV	3.00	4.00	5.00	6.00	7.00	8.00
V	2.00	2.75	3.50	4.25	5.25	6.00

Table III

Threat Summary

THREAT	EFFECT
Simultaneous Launch:	
SLBM vs. Bombers	Safe-escape bombers airborne, most U.S. missiles launched after first hits received.
SLBM vs. Missiles	All U.S. bombers airborne. some missiles launched.
Simultaneous Arrival	All U.S. bombers airborne, missiles dependent on SLBM targeting.
Simultaneous Detection ...	Safe-escape bombers airborne, fewer U.S. missiles launched due to shorter interval between SLBM and ICBM arrival.
SLBM Pindown	All U.S. bombers airborne, enemy capability to pindown all U.S. missiles questionable.
Other Enemy Capabilities:	
MRV	Increased destruction area of single targets, use of decoys to confuse ABM defenses.
MIRV	Capable of destroying several targets with independently targeted warheads deployed from a single launch vehicle.
FOBS	Less warning time, few detection systems for penetration from the south.
Orbiting Launch Pad ...	Possible targeting of any place on earth, little warning time, no current vulnerability.
Value Targeting	Intended to cripple major U.S. information and communication systems, industries and population centers, and hamper ability of U.S. to conduct a war.

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IV. The Model

A staff officer renders no service to
the country who aims at ideal standards,
and thereafter simply adds and multi-
plies until impossible totals are
reached.
                    Winston Churchill
                    15 October 1940
                    Ref 29:254

A model will now be developed to aid in the analysis

of force survival. This will allow the comparison of

various basing alternatives, as well as sensitivity tests

to determine the effects of changing the various parameters

which can be controlled. The mc̄ ̣l will be relatively

simple so that answers can be obtained without the aid of

computers or calculators. If cost information were avail-

able, it would be feasible to determine where the greatest

gain in force survival could be made for the least possible

cost.

Safe Escape Distance

The first step will be to determine the distance (D)

to which an aircraft must fly to be considered safe. This

distance is governed by the size of the weapon used by

the enemy and the ability of the aircraft to withstand

the effects of a nuclear explosion. This capacity to

resist the effects of blast, thermal flash, and initial

radiation will be referred to as "hardness". For a more

complete explanation of the various nuclear weapons

effects, see Appendix A.

Figures 3 and 4 depict the requ   i distance for an aircraft to fly to escape the lethal envelope. Figure 3 represents the lethal radius of the weapon if detonated at the center of the runway. Figure 4 shows the critical region with aircraft flight path, height of the mach stem, and the shock front.

Whether or not the aircraft is exposed to the higher overpressures in the mach region will be determined by its ability to climb above the height of the mach stem on its escape flight path. Also, the area just above the triple point would subject the aircraft to two shocks in rapid succession which could possibly be as undesirable as the mach stem.

Soft Targets

In military parlance, air bases are soft targets, meaning that all of the buildings and parked aircraft are extremely vulnerable to the effects of air blast. Tests in Nevada have indicated that complete destruction of aircraft occurs at peak blast overpressures in the vicinity of 5 pounds per square inch (psi). In addition, the light industrial type buildings and the residential construction characteristic of Air Force bases are damaged very severely, or destroyed completely, by this same blast overpressure. Thus, in general, the weapon to be used against an air base is selected to create at least 5 psi of blast overpressure over the entire working area of the base (Ref 38:167).
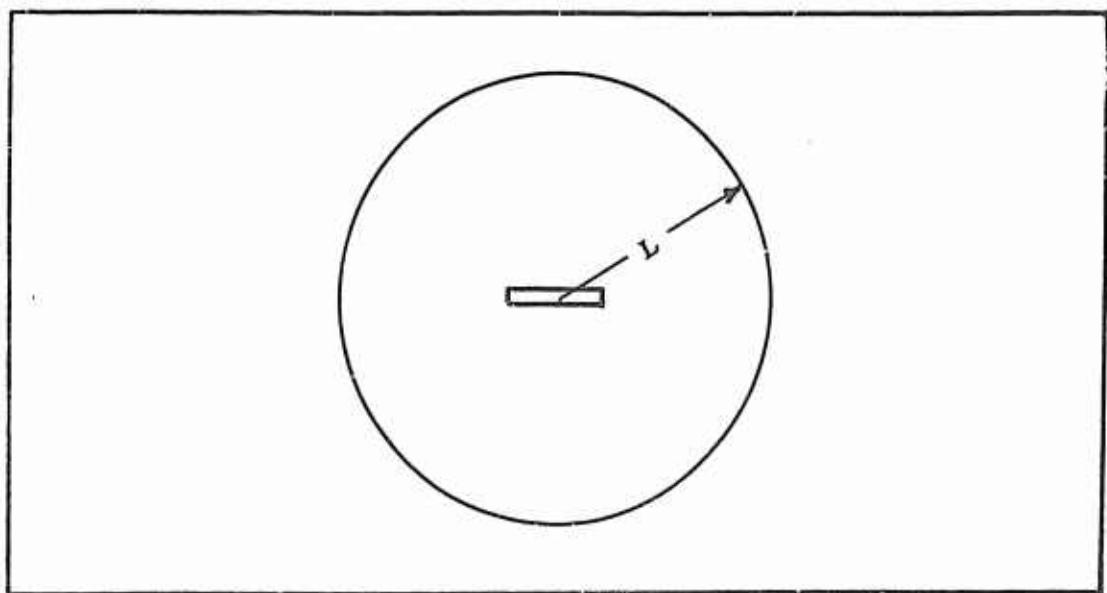
Figure 3. Lethal Radius of Weapon
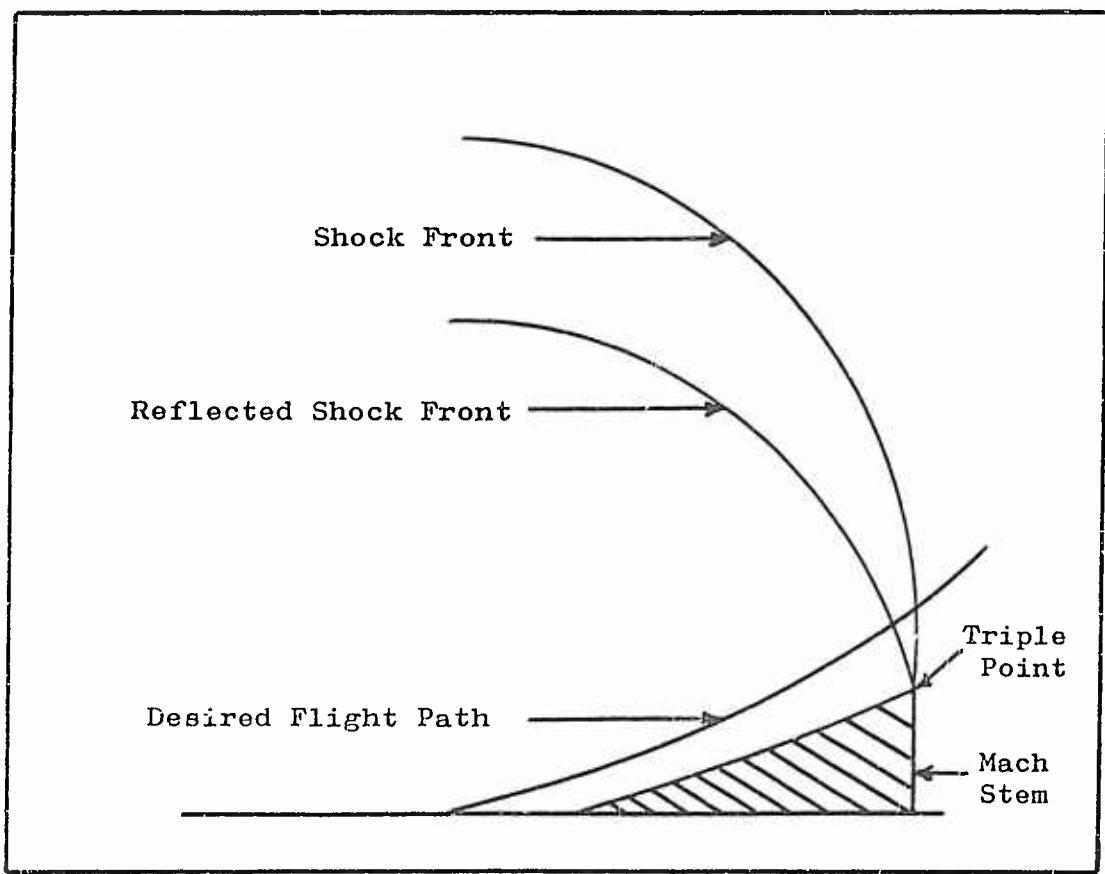
Figure 4. Aircraft Escape Path

The important target area of a typical American bomber base usually averages about 12 to 13 square miles. This corresponds to the area enclosed by a circle about 2 miles in radius (Ref 44:165).

The aiming point on each air base is taken to be the center of the principal runway. The bomb yield is then computed so that it creates a blast overpressure of at least 5 psi everywhere within the target area circle which has a radius of 2 miles.

Air bases are area targets, in contrast to point targets. The general firing problem against an air base is as shown in Figure 5.
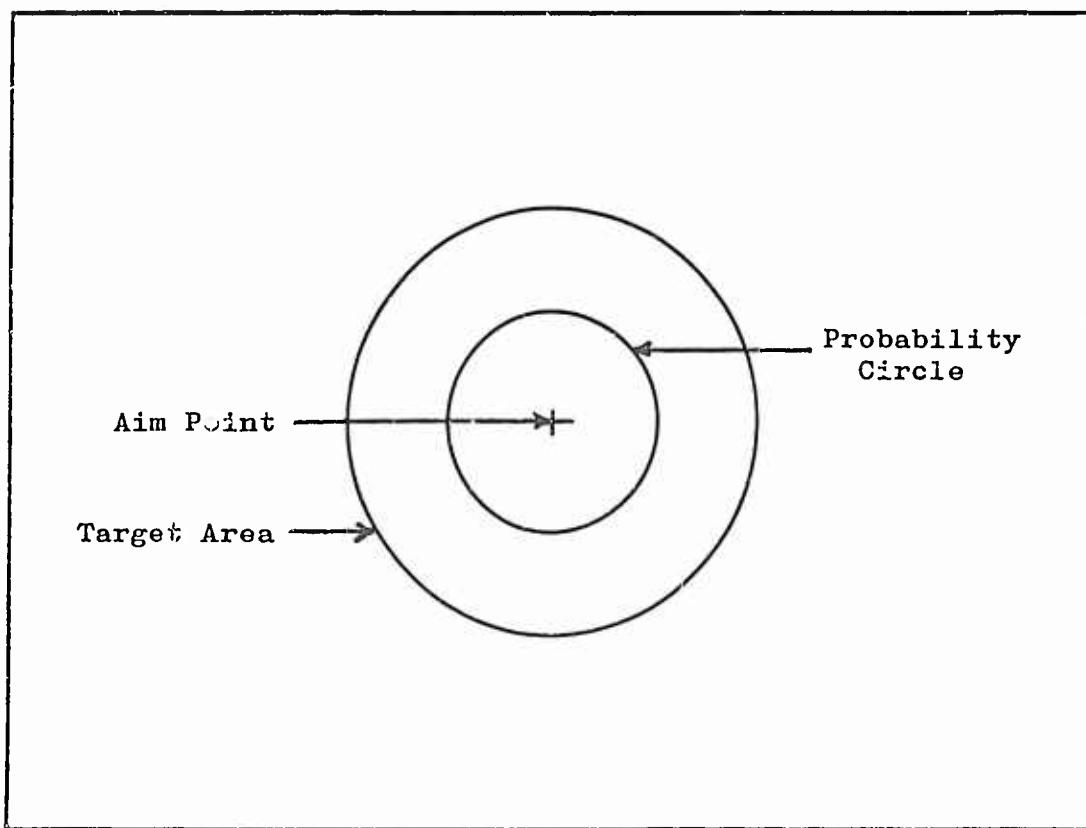
Figure 5. General Firing Problem

This shows the area of the air base as a circle with a radius of 2 miles drawn with the aiming point as its center. The smaller circle encloses the region of radius (R) within which there is a probability (P) that the weapon would strike (Ref 44:169-170).

Computational Aids

As a convenience to those interested in the effects of nuclear weapons, the Lovelace Foundation designed a circular computer to make effects data easily available. Taken from The Effects of Nuclear Weapons (Ref 26), the information on the computer shows the many environmental variations associated with nuclear detonations that present a potential hazard to man. The Lovelace computer was used throughout this study to simplify necessary calculations for the numerous situations presented. Many of the mathematical formulas and charts upon which the Lovelace computer is based are presented in Appendix A.

Another computer aid used in this study is "The Missile Effectiveness and CEP Calculator". It was developed by General Electric-Radio Guidance Operation, Defense Electronics Division, Syracuse, New York.

The purpose of the Missile Effectiveness and CEP Calculator is to provide the system designer with a means of quickly evaluating the effect of changes in various weapon system parameters on the performance of the system (Ref 47).

The Missile Effectiveness Calculator is used to show

the surface burst lethal radius of a weapon when used

against point targets of specified hardness, and to

convert this to a single shot kill probability (SSKP)

for a range of circular probable errors (CEP). It also

gives the cumulative kill probability when more than one

weapon is fired against a target. The supporting

mathematical details for the computer can be found in

Appendix 6 of Strategy for Survival (Ref 44).

For any given CEP, the lethal radius in nautical miles

for point targets (i.e. the center of an area target) can

be obtained from the General Electric computer. The CEP,

which also stands for the circle of equal probability,

is the area within which 50% of the missiles will strike.

The probability (P) of a hit with a single weapon against

a single point target can be written in terms of the

weapon lethal radius (L) and the CEP as:

$$P = 1 - e^{-0.693(\frac{L}{CEP})^2}$$

This equation has been solved for various lethal

radii and CEP's (solutions can also be obtained from the

General Electric computer), and some of the results are

shown in Table IV (Ref 44:335).

Kill Probability and Circular Probable Error

One must next determine what kill probability the

enemy desires, and thus calculate the lethal radius (L)

required for point target destruction. Table V gives the

lethal radius required for selected enemy desired kill

probabilities (P) and various CEP's.

Table IV

Probability of a Hit Against a Single
Point Target by a Single Weapon

Lethal Radius	CEP = $\frac{1}{2}$ mile	CEP = 1 mile	CEP = 2 miles
0.50	50.0	16.0	4.0
0.75	79.0	32.0	9.0
1.00	94.0	50.0	16.0
1.50	99.8	79.0	32.0
2.00	99.9	94.0	50.0
2.50	100.0	98.0	66.0
3.00	100.0	99.8	79.0
4.00	100.0	100.0	94.0

Table V

Lethal Radius for Point Targets

Probability (P)	CEP = $\frac{1}{2}$ mile	CEP = 1 mile	CEP = 2 miles
80%	0.75	1.50	3.00
85%	0.83	1.65	3.40
90%	0.90	1.83	3.60
95%	1.10	2.10	4.20

Table V is similar to Table IV, except that in Table V the probability (P) is fixed and the required lethal radius is calculated for various CEP's. Table V indicates, for example, that for a CEP of one mile and a desired kill probability of 85%, the weapon used must

have a lethal radius of at least 1.65 miles. This

radius corresponds to that of an 85% probability circle

(similar to a CEP which is a 50% probability circle)

centered at the aim point. The weapon size must allow

for an impact anywhere in the circle, and the worst case

is on the rim of the circle. Figure 6 shows the area of

destruction when a weapon impacts on the rim of the prob-

ability circle. The minimum lethal radius of the weapon

must equal the radius of the probability circle $(L = R)$.
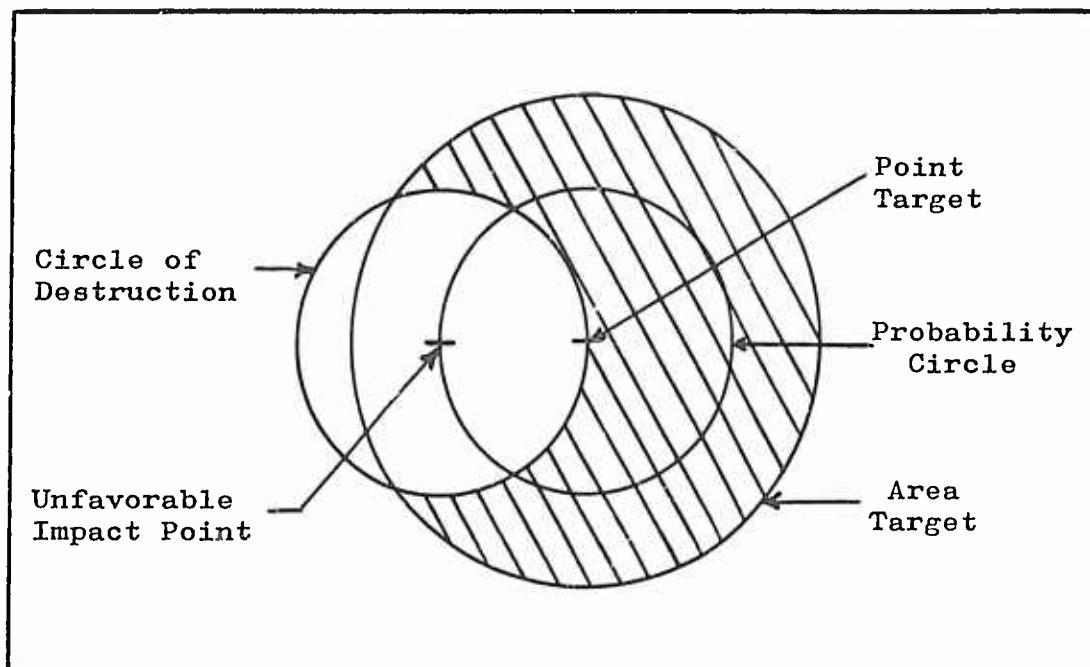
Figure 6. Unfavorable Impact Location for Point Target

Targeting Air Bases

Air Force bases are area targets. It is easily seen

that the shaded part of the area target in Figure 6 will

not be hit by the desired 5 psi under the above conditions.

Therefore, for targeting air bases, the blast destruction

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must reach from the most unfavorable impact point out-
ward to the farthest point of the target area (Figure 7).
This requires that the 5 psi blast overpressure be produced
over a distance equal to the sum of the radii of the two
circles, i.e., L = 2 + R (Ref 44:170).
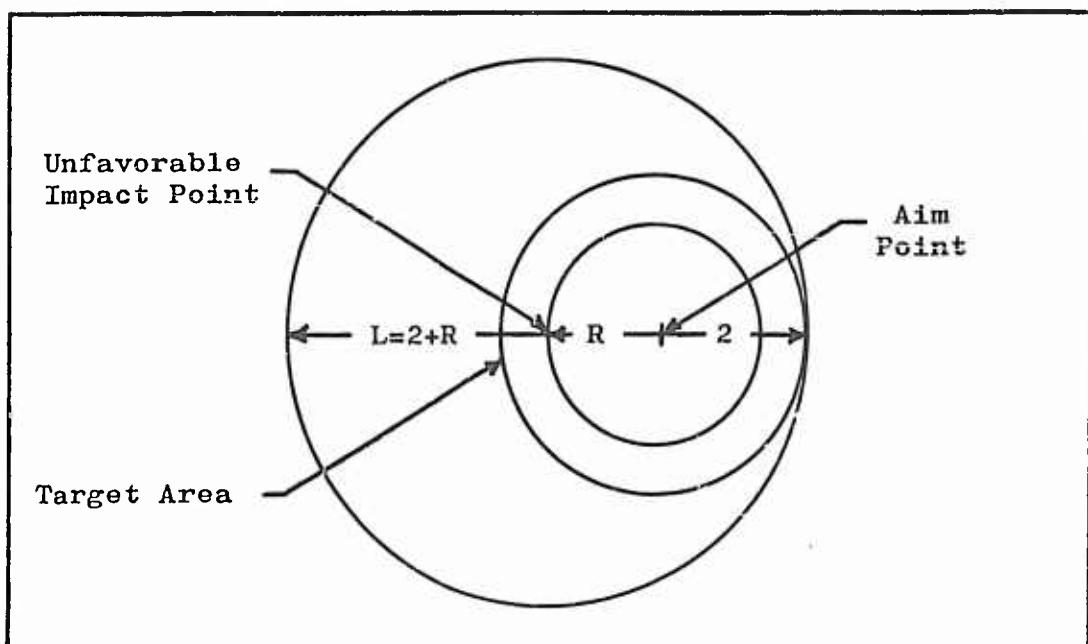
Figure 7. Unfavorable Impact Location for Area Targets

The required weapon lethal radii (L) for area targets
then becomes two plus the values of Table V. Table VI
gives these values.

Table VI

Required Lethal Radii for Area Targets (miles)

Probability (P)	CEP = $\frac{1}{2}$ mile	CEP = 1 mile	CEP = 2 miles
80%	2.75	3.50	5.00
85%	2.83	3.65	5.40
90%	2.90	3.83	5.60
95%	3.10	4.10	6.20

The lethal radius (L) in miles can be calculated for various weapon yields from the Lovelace computer. These radii are summarized in Table VII.

Table VII

Weapon Lethal Radii Available

Bomb Yield (MT)	Lethal Radius Air Burst(mi)	Lethal Radius Surface Burst(mi)
0.1	2.0	1.3
0.5	3.4	2.2
1.0	4.3	2.8
2.0	5.4	3.4
5.0	7.4	4.7
10.0	9.3	5.9

Weapon Assumption

A comparison of the lethal radii available (Table VII) and the required lethal radii (Table VI) indicates that destruction of a bomber base may be achieved by an air burst or a surface burst of 2 - 5 MT. Considering the payload capability of the SLBM, the air burst is more advantageous to the attacker since he could use bomb yields of 2 MT or less and destroy most bases.

With this in mind, the following assumption will now be made. A weapon of 2 MT or less yield will be detonated at optimal altitude to provide 5 psi over-pressure over the entire 2 mile radius of the target.

For a single warhead it can be seen that the escape distance (D) to which the aircraft must fly to be safe

for the worst case is D = L + R. For a cluster of warheads (MRV) the determination of escape distance is more complex and will be developed along with the determination of D for the single warhead case.

Optimal Burst Height

For purposes of this study a determination of the optimal burst heights must be made. From Figure 31 in Appendix A, the optimal height of burst for a 1 KT yield and 5 psi overpressure is 1000 feet, and the distance it reaches from ground zero is 2280 feet. This relationship scales as the cube root of the yield (Figure 29, Appendix A). These relationships and the Lovelace computer were used to calculate the heights of burst and lethal radii shown in Table VIII.

Table VIII

Optimal Height of Burst

Yield (MT)	Height (feet)	5 psi Radius (miles)
0.1	4,650	2.00
0.5	7,900	3.40
1.0	10,000	4.32
2.0	12,500	5.41

Mach Stem

The height of the mach stem can be calculated from the various weapon yields and lethal radii given in Table VIII (formulas in Appendix A). These values are

shown in Figure 33 of Appendix A for a 1 KT yield. This figure shows that the mach stem commences at 0.13 miles and the height of the mach stem is dependent upon the distance from the point of burst. Heights of the mach stem for yields other than 1 KT are shown in Table IX.

Table IX

Height of Mach Stem

Yield (MT)	5 psi Radius (miles)	Stem Height (feet)
0.1	2.00	650
0.5	3.40	1100
1.0	4.32	1400
2.0	5.41	1750

Desired Flight Path

It is readily seen that the height of the mach stem is small in relation to the distance from the point of burst. This implies that the escaping aircraft could be at an altitude greater than the height of the mach stem. The aircraft should plan its flight path so as to be sufficiently above the triple point to avoid receiving two shocks within a very short interval. This is illustrated in Figure 8.

Shock Wave Travel Time

Next it is necessary to compute the time for the shock wave to travel L miles and the change in overpressure due to altitude (if any).
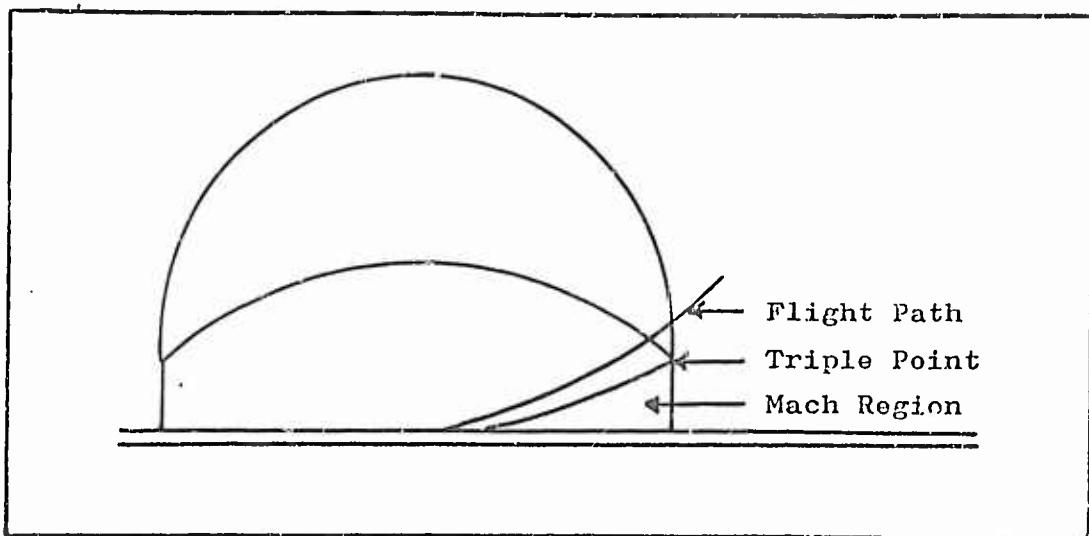
Figure 8. Desired Aircraft Flight Path

Note that for the 1 MT and 2 MT detonations the air-
craft may not be near coaltitude with the center of the
burst. Consequently, the time of arrival of the shock
wave will be between the arrival time in the stem and the
coaltitude time. Likewise, the overpressure at the height
of the aircraft will be slightly greater than the coalti-
tude overpressure, yet somewhat less than the stem over-
pressure. A rough interpolation should be sufficient in
this region due to the small range of allowable values.

It should also be noted that for the 100 KT and
500 KT detonations the optimal height of burst is between
4000 feet and 8000 feet. Since this would be near the
height of the aircraft, no altitude corrections need be
calculated.

The coaltitude pressure (p) and the shock arrival
time (s) can be determined for various weapon yields and
heights of burst using the following equations (for a more

complete description see Appendix A):

$$p = p_1 \left(\frac{p}{p_o} \right)$$

$$s = s_1 W^{1/3} \left(\frac{p_o}{p} \right)^{1/3} \left(\frac{T_o}{T} \right)^{1/2}$$

The coaltitude pressure can be calculated directly and the results for yields of 1 MT and 2 MT are shown in Table X. To find s, the shock arrival time, it is first necessary to determine s_1, the shock arrival time for a 1 KT burst. For example, to compute the value of s for a 2 MT weapon, first compute the corresponding burst height for a 1 KT weapon:

$$h_1 = \frac{h}{W^{1/3}} = \frac{12500}{(2000)^{1/3}} = 1000 \text{ feet}$$

The corresponding distance from ground zero for 1 KT is:

$$d_1 = \frac{d}{W^{1/3}} = \frac{26400}{(2000)^{1/3}} = 2100 \text{ feet}$$

From Figure 32 (Appendix A) the shock arrival time for a 1 KT burst at a height of burst of 1000 feet and at a distance of 2100 feet from ground zero is approximately equal to 1.5 seconds. The corresponding arrival time for a 2 MT yield is:

$$s = s_1 W^{1/3} = 1.5(2000)^{1/3} = 18.75 \text{ seconds}$$

The coaltitude correction is:

$$s = s_1 W^{1/3} \left(\frac{p_o}{p} \right)^{1/3} \left(\frac{T_o}{T} \right)^{1/2} = 23 \text{ seconds}$$

These values are summarized in Table X.

Table X

Coaltitude Overpressure and Arrival Time

Weapon Yield (MT)	Stem Overpressure (psi)	Coaltitude Overpressure (psi)	Stem Arrival (sec)	Coaltitude Arrival (sec)
1	5	3.44	17.50	21
2	5	3.12	18.75	23

These values imply that the overpressure at the aircraft location is between the coaltitude values and the 5 psi in the stem. Also, the arrival time for the shock wave for each yield is between these tabled values. For purposes of illustration it is desirable to arbitrarily select an overpressure (hardness) which the aircraft in question can withstand. Because of the similarity in the coaltitude overpressures for the 1 MT and 2 MT yields, 3 psi is selected as the example aircraft hardness. The selection of this value is convenient as it allows a slight extension of the range specifications and the interpolated coaltitude times, thus approaching the actual coaltitude values calculated.

Determination of the 3 psi range and time for the 100 KT and 500 KT yields can be done by formula, or by the Lovelace computer. These results are summarized in Table XI.

Escape Distance

It is now possible to calculate the distance (D) to which an aircraft must travel to be safe, and the time (S)

Table XI

Range and Time for 3 psi

Weapon Yield (MT)	Lethal Radius (mi)	Overpressure at Aircraft (psi)	Shock Arrival (sec)
0.1	2.8	3	12
0.5	4.8	3	20
1.0	5.0	3	21
2.0	6.0	3	23

for the shock wave to travel this distance for the worst possible case. It is necessary to select arbitrary values for the CEP and the desired enemy kill probability (P). This will allow a determination of the required lethal radius (L) and the radius (R) which can be used in the various footprint patterns to determine the maximum escape distance required. For the purposes of this study, let the enemy selection of P be 95% and the CEP be one mile. This would give footprints of 5 psi over the target area and 3 psi lethal aircraft radius for the 1 MT and 2 MT cases as shown in Figure 9.

For smaller weapon cluster attacks, calculations for the MRV deployment are based on the center of the array of deployed warheads as ground zero. The Polaris A-3 SLBM is capable of carrying either a 1 MT warhead or three 200 KT warheads (Ref 2:73). Assuming that the clusters used by the enemy consist of either three 100 KT warheads or three 500 KT warheads, the footprints of the clusters would appear as shown in Figure 10.
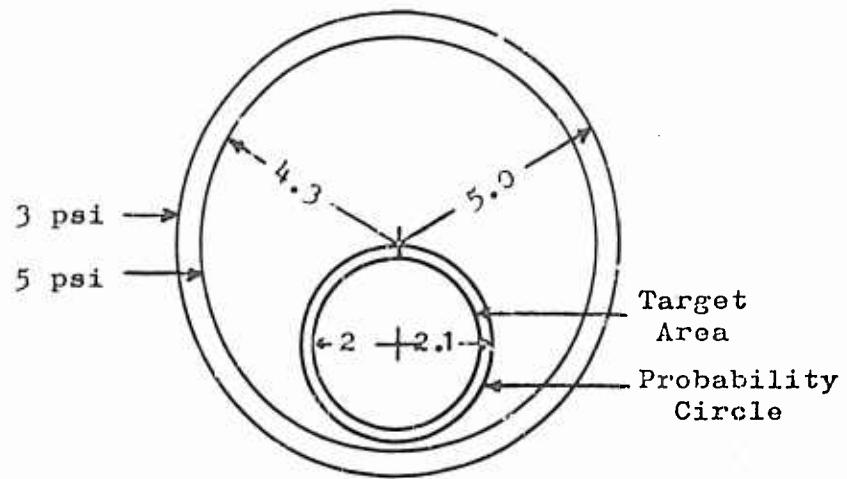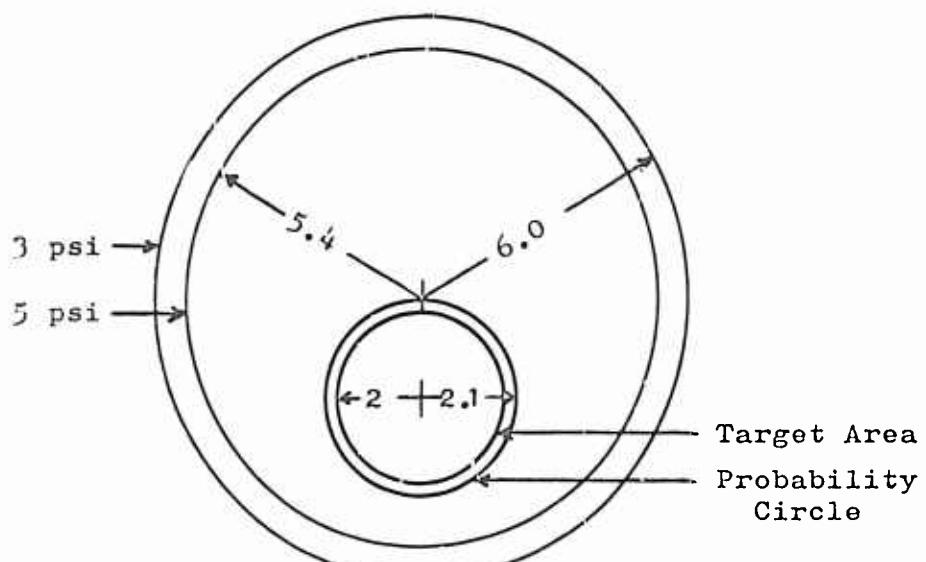
Figure 9. Escape Distance (D), Worst Case for 1 MT & 2 MT
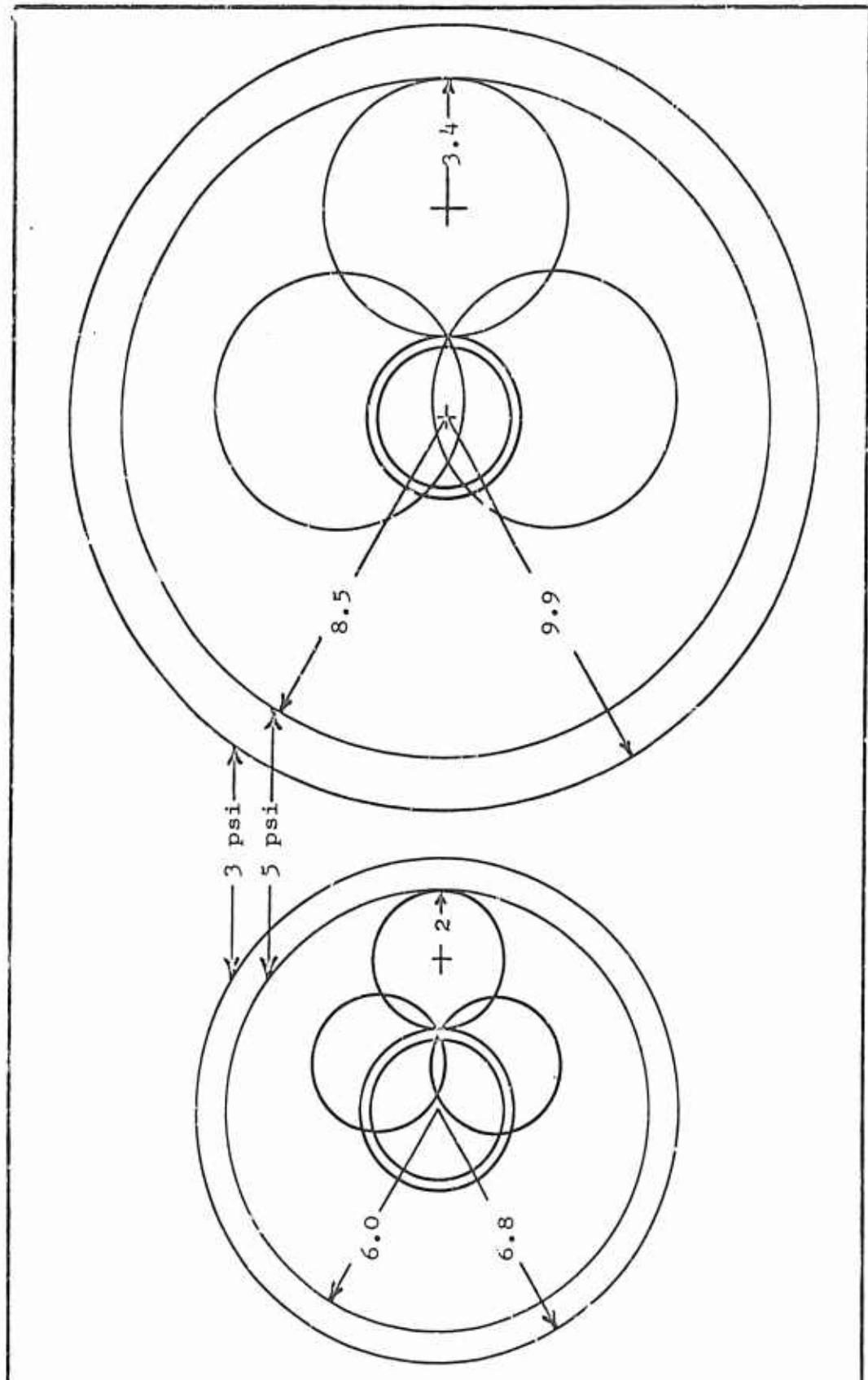
Figure 10. Escape Distance (D), Worst Case for 3x100 KT and 3x500 KT Weapons

It is apparent from each of these diagrams that the allowance for the worst case may be somewhat severe and unrealistic. For instance, the worst case for 1 MT calls for the detonation of the weapon on the outer ring of the probability circle, thus implying an escape distance of 7.1 miles (Figure 9). However, this is only going to be the case when the aircraft flight path is in the direction of the weapon detonation. Should the flight path be in any other direction, especially opposite the direction of the weapon detonation, the escape distance would be less. The same condition also holds for the cluster attack. For this reason it is desirable to assume a direct hit and calculate the escape distance (D) to be equal to the lethal radius (L) of the various weapon attacks. Then one can further show what the conditions would be if the aircraft were in fact flying in the worst case direction. Figures 11, 12 and 13 illustrate these concepts.

The distances in Figures 11 and 12 for the lethal radius and aircraft safe escape are shown in Table XII which summarizes data to be used in the remainder of this study.

Table XII

Data to be Used in Example

Weapon Yield (KT & MT)	Lethal Radius (miles)	Shock Arrival (seconds)
3x100 KT	5	12
3x500 KT	8	20
1 MT	5	21
2 MT	6	23
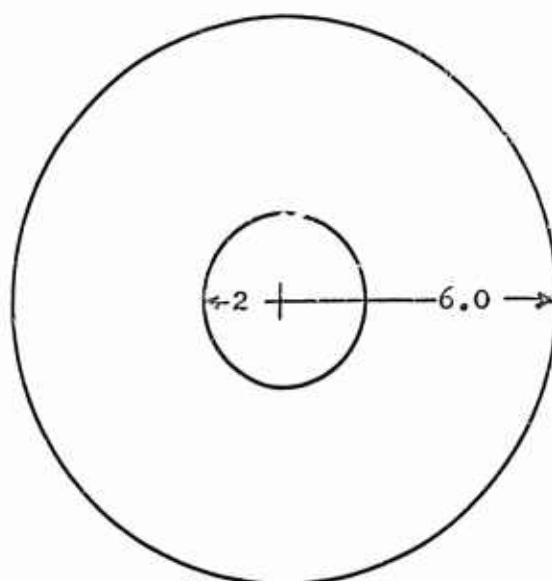
Yield = 2 MT, D = 6.0 miles
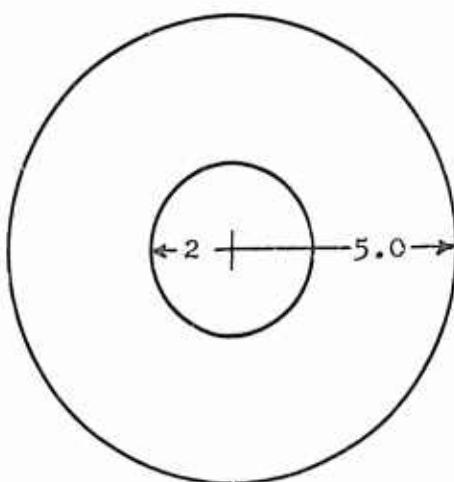
Yield = 1 MT, D = 5.0 miles

Figure 11.   3 psi Range, Direct Hit for 1 MT & 2 MT
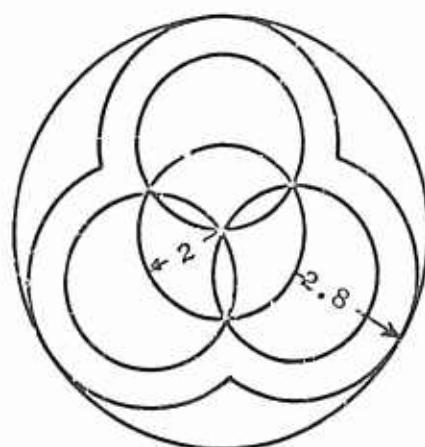
Yield = 3x100 KT, D = 4.8 miles
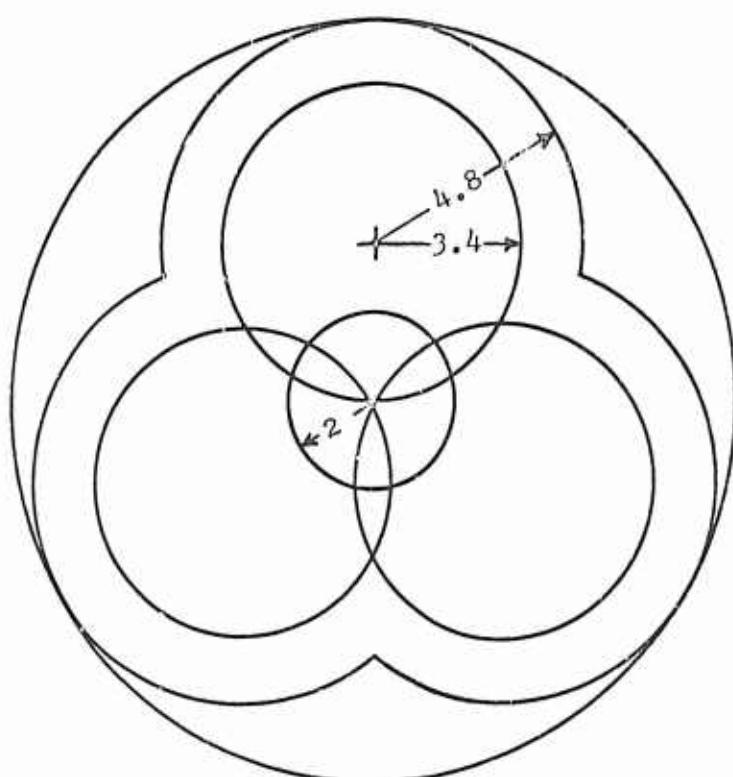
Yield = 3x500 KT, D = 8.2 miles

Figure 12. 3 psi Range, Direct Hit for 3x100 KT & 3x500 KT
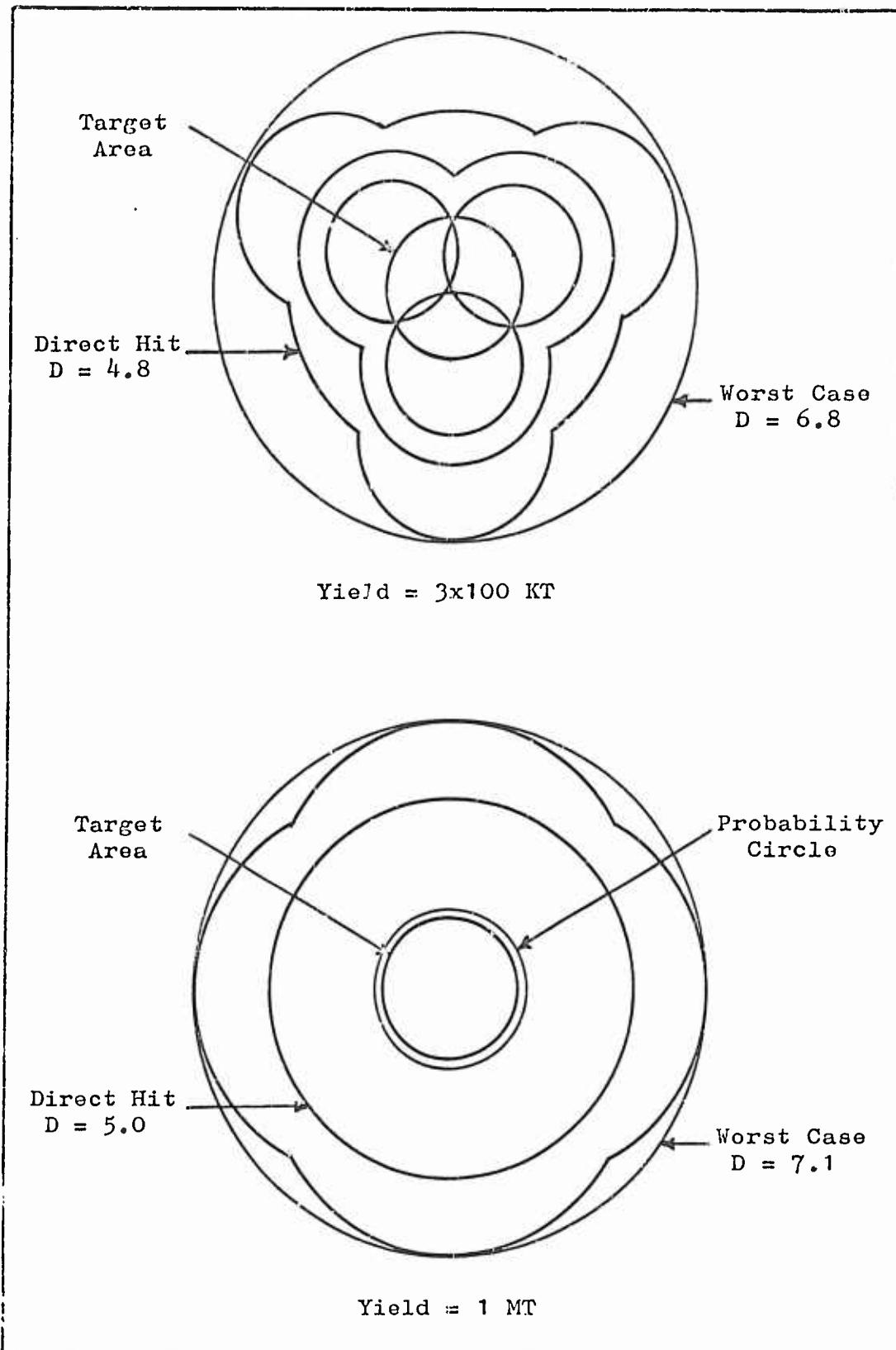
Figure 13. Aircraft Flight Path for Worst Case

Since Table XII shows the eight mile radius to be
the most severe, this is the value which will be used
for the safe escape distance in the example. If other
warheads are known to be aboard enemy SLBM's, the appro-
priate distance can be used.

As stated previously, the selection of 3 psi over-
pressure for the lethal limit was arbitrary. Figure 14
illustrates the effect of a change in the lethal over-
pressure. These values would depend on the hardness
characteristics of the aircraft in question. For lower
aircraft hardness, the distance the aircraft must travel
to be safe is greater, and the corresponding shock arrival
time is longer.
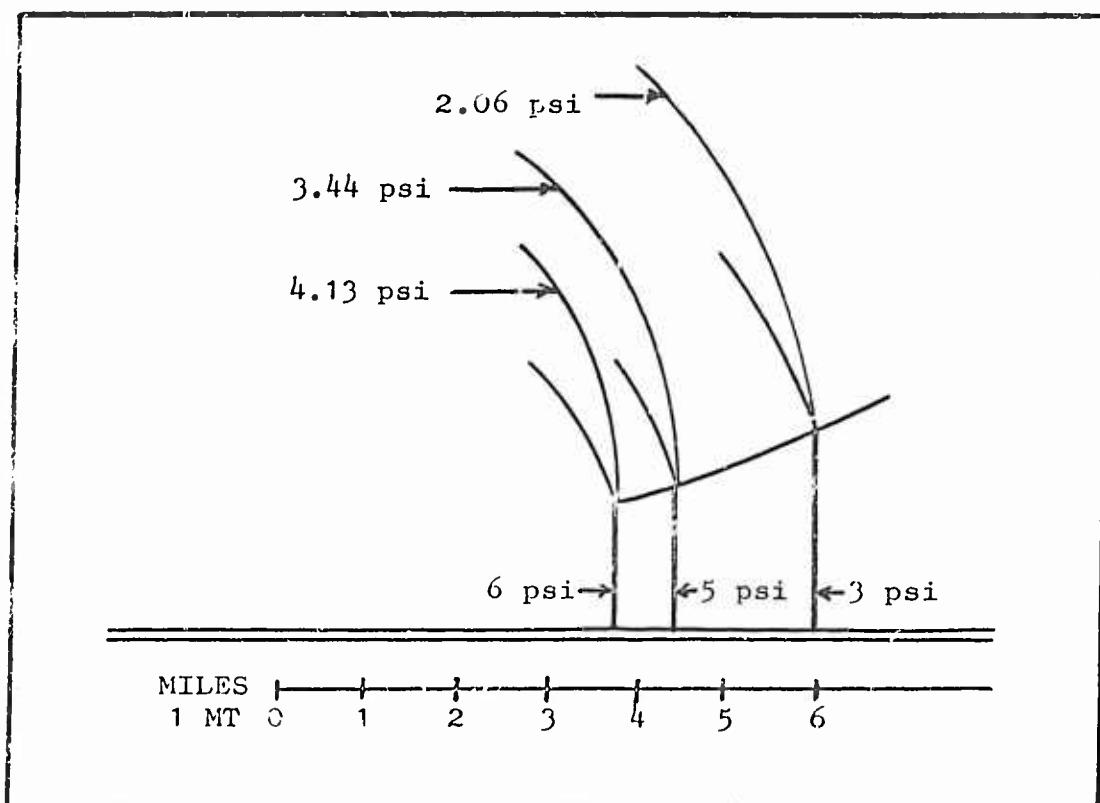
Figure 14. Effect of Aircraft Hardness on Escape Distance

Survival Time

Once the safe escape distance has been determined,
the time to takeoff and fly this distance can be computed
from the performance tables in the applicable technical
order (the "dash one") for any given aircraft. Further
development of the model requires a determination of the
other parameters critical to prelaunch survival. These
include missile detection, warning, crew reaction, and
aircraft reaction times. The sum of these five times
is the critical time period (T) required for an aircraft
to survive a surprise attack.

Man has some control over each of these critical
times. Detection time depends on the capabilities of
radars or other detection equipment, and their operators.
Warning time depends on the command and control system
and its supporting communications network. The state of
alert of the crew members and their proximity to the
alert aircraft governs crew reaction time. Aircraft
reaction is dependent on engine start and systems warm-
up times, plus the proximity of the aircraft to the take-
off position on the runway. The time to fly to a safe
distance depends on the performance and hardness charac-
teristics of the particular aircraft.

For purposes of the model, let T equal the sum of
the t_k, $k = 1,2,3,4,5$. These t_k are the five critical
times over which the defending force has some control,
and which determine prelaunch survival time.

The equation for T may be written:

$$T = \sum_{k=1}^{5} t_k, \quad \text{where}$$

t_1 = detection time (from missile launch to detection by radar or other means)

t_2 = warning time (from detection to crew alert)

t_3 = crew reaction time (from alert notification to ready for engine start)

t_4 = aircraft reaction time (from start engines to takeoff position on the runway)

t_5 = flight time to safe escape distance (time to fly distance D, previously developed)

Survival Equation

The parameters developed to this point can be used to calculate the number of aircraft which can survive on a given airfield against a given threat. Using the threat data from Figure 1 and the contour chart in Figure 2, let a_{ij} equal the number of aircraft which can survive on an airfield in zone i when confronted with threat j. The reason for the subscripts will be made apparent in later calculations for total force survival and are introduced here for uniformity.

The following equation will give the desired result:

$$a_{ij} = \frac{60}{I}(M - T) + \frac{S}{I} + 1$$

where I = aircraft launch interval (in seconds)

M = missile time of flight (in minutes)

$T = \sum_{k=1}^{5} t_k$, the sum of critical times (in minutes)

S = time (in seconds) for the shock front to travel the escape distance

Note: a_{ij} is the positive integer part of the solution, i.e., 6.34 = 6, 0.78 = 0, etc. (Ref 70:461)

The formulation is straight forward and easily understood. Sixty seconds divided by the launch interval gives the number of aircraft which begin their takeoff roll in one minute. The missile time of flight is proportional to the distance it must fly to reach its intended target, and thus is determined by the zone in which the target airfield lies and the distance from the coastline to the point of missile launch.

Subtracting the sum of the times critical to pre-launch survival (T) from the missile time of flight (M) gives the time available for the aircraft to escape. Since T includes the flight time to safe escape distance, the difference (M - T), when multiplied by the number of aircraft launching per minute $(\frac{60}{I})$, yields the number of aircraft which get outside the lethal radius (D = L) before weapon detonation.

An additional short period of time available to escaping aircraft is the time (S) for the shock front to travel the lethal radius distance after detonation. When this time is divided by the launch interval $(\frac{S}{I})$, the result is the number of additional aircraft which can escape.

If the one aircraft which just reaches the safe

escape distance is considered to get away safely, it must
be accounted for in the equation by adding one.

Summation of the aircraft which can get outside the
lethal radius before warhead detonation, aircraft which
can escape during the time for the shock front to travel
the lethal radius, and the one aircraft which just makes
the safe escape distance, gives the total number of air-
craft which can survive on one airfield against one threat.

Since solution of the equation can result in non-
integer answers, a decision rule is adopted to use only
the positive integer part of the answer. The reason for
this rule is the so called "cookie cutter" approach.
This approach to the problem requires that any aircraft
at or beyond the lethal radius survives. Fractional
parts of aircraft surviving have no useful meaning.

Survival Matrix

Using the survival equation just developed to deter-
mine the number of aircraft which can survive a surprise
enemy attack while stationed in any particular zone, one
can now proceed to determine total bomber force survival
in the following manner. Given any m zones (determined
by distance contours from the United States coastlines)
and any n threats (determined by known or suspected enemy
missile capabilities), calculate the number of aircraft
$(a_{j,j})$ which can survive in zone i $(i = 1,2,...,m)$ when
confronted with threat j $(j = 1,2,...,n)$. Arrange these
values in standard matrix form (Ref 27:60-71 & 25:20-21).

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The result is the m x n aircraft survival matrix A.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2j} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mj} & \cdots & a_{mn} \end{bmatrix}$$

Then form the bomber beddown matrix B, which is a one by m matrix with elements (b_i) determined by the number of airfields in zone i which are used to bed down bombers on alert.

$$B = \begin{bmatrix} b_1 & b_2 & \cdots & b_i & \cdots & b_m \end{bmatrix}$$

The product of these matrices (BA) is the force survival matrix F, where each element (f_j) represents the number of bombers surviving in the total force given threat j.

$$BA = F = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_j \\ \vdots \\ f_n \end{bmatrix}$$

In the following example problem and the analyses in the next chapter, it is assumed for ease of computation that the enemy submarines launch their missiles at a distance of 100 nautical miles from the United States coastlines. As previously noted, the contour lines on Figure 2 are 200 nautical miles apart. Using the middle of each contour interval as the distance from the coastline to each base in that interval, the missile ranges will be in increments of 200 nautical miles, i.e., all bases in the interval from the coastline to the first contour line are considered to be 200 nautical miles from the point of missile launch. For more precise calculations, should they be necessary, the exact distance from the enemy SLBM launch point to any given base could be used (if known). For the purpose of the examples in this study, the arbitrary intervals of 200 nautical miles will suffice.

Example Problem

For purpose of illustration, the above model will be used to determine total bomber force survival if only existing and currently planned SAC bomber bases and satellite dispersal bases are to be used for bomber beddown. The following bomber beddown matrix was developed using these known bases and the information in Appendix B applied to Figure 2 (Ref 61:5 & 74:27).

$$B = \begin{bmatrix} 21 & 9 & 13 & 2 & 2 & 1 \end{bmatrix}$$

Recall that each element of this matrix (b_i) represents the number of bases in zone i.

The weapon used in this example is a 3x500 KT MRV warhead. This implies that the safe escape distance (D) is eight miles and the shock front arrival time (S) is twenty seconds. Calculations will be made for aircraft launch intervals (I) of fifteen seconds, ten seconds, and five seconds.

It is also necessary to establish values for the t_k times in order to determine the critical time period (T). Two values of T are shown in this example so that changes in these times can be compared. Hypothetical times for the example are shown in Table XIII.

Table XIII

Values of t_k and T

t_k	Description	Case 1 (min)	Case 2 (min)
t_1	Detection Time	1.0	0.50
t_2	Warning Time	0.5	0.25
t_3	Crew Reaction Time	2.0	1.50
t_4	Aircraft Reaction Time	2.5	2.25
t_5	Escape Flight Time	2.5	2.00
T	Summation of t_k	8.5	6.50

For Case 1 the survival formula would be:

$$a_{ij} = \frac{60}{I}(M - 8.5) + \frac{20}{I} + 1$$

This formula is then used to develop the following three aircraft survival matrices for different launch intervals.

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$$A_{(I=15)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 5 & 0 & 0 & 0 & 0 \\ 11 & 5 & 0 & 0 & 0 \\ 18 & 10 & 3 & 0 & 0 \\ 24 & 16 & 8 & 0 & 0 \end{bmatrix}$$

$$A_{(I=10)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 7 & 0 & 0 & 0 & 0 \\ 16 & 7 & 0 & 0 & 0 \\ 27 & 15 & 4 & 0 & 0 \\ 36 & 24 & 12 & 0 & 0 \end{bmatrix}$$

$$A_{(I=5)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 14 & 0 & 0 & 0 & 0 \\ 32 & 14 & 0 & 0 & 0 \\ 53 & 29 & 8 & 0 & 0 \\ 71 & 47 & 23 & 0 & 0 \end{bmatrix}$$

Post multiplying the bomber beddown matrix (B) by each aircraft survival matrix (A) above gives the following three force survival matrices (F) for the different launch intervals (I): BA = F.

$$F_{(I=15)} = \begin{bmatrix} 147 \\ 46 \\ 14 \\ 0 \\ 0 \end{bmatrix}, \quad F_{(I=10)} = \begin{bmatrix} 213 \\ 68 \\ 20 \\ 0 \\ 0 \end{bmatrix}, \quad F_{(I=5)} = \begin{bmatrix} 423 \\ 133 \\ 39 \\ 0 \\ 0 \end{bmatrix}$$

For purposes of comparison, note that in the example the number of aircraft in the total bomber force which

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could survive with a fifteen second aircraft launch interval is 147 against Threat I, 46 against Threat II, 14 against Threat III, and none against Threats IV and V. Also note the effect of the launch interval. Against Threat III the bomber force which could survive is 14 if the aircraft launch interval is 15 seconds, 20 if the interval is 10 seconds, and 39 if the interval is 5 seconds.

In Case 2 of this example the critical time (T) is reduced to 6.5 minutes, as was shown in Table XIII. The aircraft survival formula is changed to:

$$a_{ij} = \frac{60}{I}(M - 6.5) + \frac{20}{I} + 1$$

When this formula is used to develop the aircraft survival matrices, as before, the results are as follows.

$$A_{(I=15)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 6 & 2 & 0 & 0 & 0 \\ 13 & 7 & 2 & 0 & 0 \\ 19 & 13 & 7 & 0 & 0 \\ 26 & 18 & 11 & 4 & 0 \\ 32 & 24 & 16 & 8 & 0 \end{bmatrix}$$

$$A_{(I=10)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 9 & 3 & 0 & 0 & 0 \\ 19 & 10 & 3 & 0 & 0 \\ 28 & 19 & 10 & 0 & 0 \\ 39 & 27 & 16 & 6 & 0 \\ 48 & 36 & 24 & 12 & 0 \end{bmatrix}$$

$$A_{(I=5)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 17 & 5 & 0 & 0 & 0 \\ 38 & 20 & 5 & 0 & 0 \\ 56 & 38 & 20 & 0 & 0 \\ 77 & 53 & 32 & 11 & 0 \\ 95 & 71 & 42 & 23 & 0 \end{bmatrix}$$

Post multiplying the bomber beddown matrix (B) by the aircraft survival matrices developed for Case 2 gives the following force survival matrices: BA = F.

$$F_{(I=15)} = \begin{bmatrix} 345 \\ 195 \\ 78 \\ 16 \\ 0 \end{bmatrix}, \quad F_{(I=10)} = \begin{bmatrix} 510 \\ 285 \\ 115 \\ 24 \\ 0 \end{bmatrix}. \quad F_{(I=5)} = \begin{bmatrix} 1008 \\ 558 \\ 211 \\ 45 \\ 0 \end{bmatrix}$$

Comparison of the results in Case 1 and Case 2 shows the results of a change in the critical time (T). The effect of shortening the aircraft launch interval in Case 2 is graphically illustrated in Figure 15.
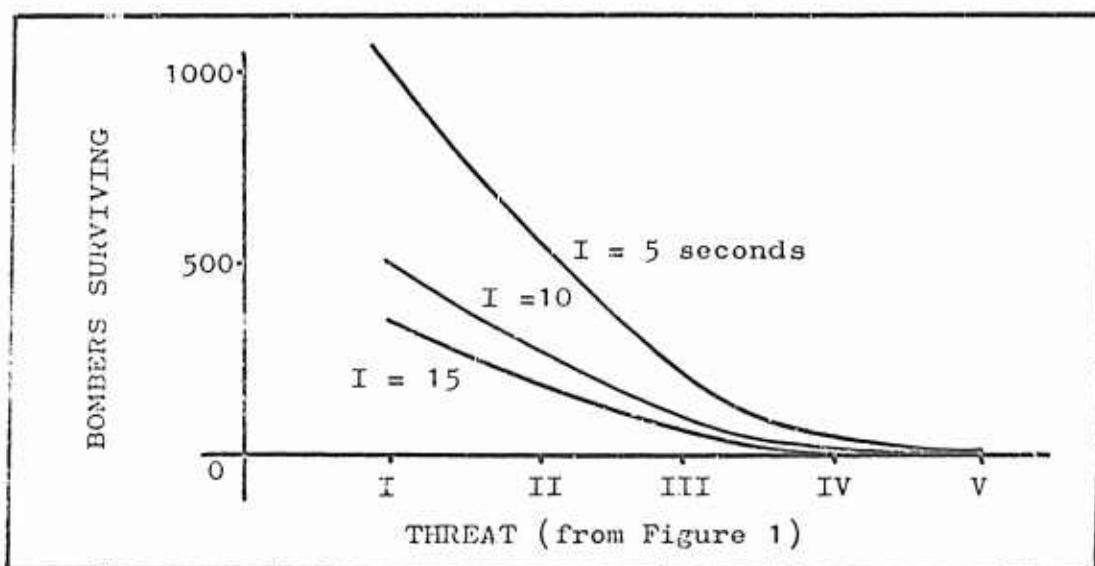

Figure 15. Effect of Bomber Launch Interval on Survival

V. Analysis of Alternatives

You will usually find that the enemy has
three courses open to him, and of these
he will adopt the fourth.
    Helmuth von Moltke ("The Elder")
    1800-1891
    (Ref 29:80)

Utilizing the threat data presented in Chapter III

and the survival model developed in Chapter IV, several

basing alternatives can be analyzed. To assist in the

analysis and comparison of the various basing alternatives

it is necessary to specify certain variables to be held

constant throughout the analysis. Further discussion per-

taining to the effects due to changes in these variables

along with other survival improvement techniques is pre-

sented later in this chapter.

The particular values arbitrarily chosen for the

various parameters are as follows. Let the distance (D),

to which an aircraft must fly to be safe, equal eight

miles and the associated shock front arrival time (S)

equal 20 seconds. The time (T) for detection, warning,

crew and aircraft reaction, and to fly out to safe

distance will be 6.5 minutes. Aircraft launch interval

(I) will be 10 seconds. Missiles time of flight (M) for

the various possible threats will be that shown in Figure 1

(summarized in Table II for the 200 nautical mile intervals

of Figure 2). Appendix B will be used for numbers of

airfields with certain runway qualifications. Information

given in Appendix B was extracted from the VFR Supplement

and the IFR Supplement to the DOD Flight Information
Publication (FLIP) published by the USAF Aeronautical
Chart and Information Center. The combined IFR and VFR
Supplements constitute a complete Aerodrome Directory
covering the United States (Ref 34 and 69).

For the purposes of comparing alternatives, Threat
III is used throughout most of this chapter. This should
not be construed to mean there is any particular signifi-
cance to this level of threat. Since Threat III repre-
sents a sort of mean in relation to the range of hypo-
thetical threat data in Figure 1, the effects of a more
severe or less severe threat can easily be seen.

All SAC Bases

The first alternative to be considered is the use of
all the existing and currently proposed SAC bomber bases
and satellite dispersal bases (Ref 61:5 and 74:27). With
the parameters previously specified, this alternative is
shown as Case 2 of the example problem in Chapter IV.
Recall that these 48 bases in the six zones of Figure 2
resulted in the B matrix: $B = \begin{bmatrix} 21 & 9 & 13 & 2 & 2 & 1 \end{bmatrix}$.
When the B matrix is post multiplied by the $A_{(I=10 \text{ sec.})}$
matrix, the result is the force survival matrix F, where

$$F = \begin{bmatrix} 510 \\ 285 \\ 115 \\ 24 \\ 0 \end{bmatrix}$$ and each f_j represents the number
of aircraft surviving threat j.

It is readily seen, for example, that in this

alternative a force of 115 bombers could survive Threat

III if all SAC bomber bases and satellite dispersal

bases are used.

One obvious advantage to using existing and currently

planned SAC bases is that no additional facility construc-

tion or communication lines need be established. Thus,

essentially no additional cost (above that already planned)

is involved.

The major disadvantage lies in the severity of the

threat. As seen from the example, if it is determined

that enemy technology becomes capable of Threat IV or

Threat V and the other parameters remained unchanged, then

either 24 bombers survive or the total force is destroyed.

All USAF Bases

To advance one step further in making more bases

available to SAC bombers, a solution is to utilize all

qualifying AF bases. By qualifying, it is meant that

there must be an acceptable runway located on the base for

the particular aircraft in question. As shown in Appendix

B there are 112 Air Force bases having runways 6000 feet

or longer, 101 with 8000 or longer, and 66 with 10,000

feet or longer. The number of bases available under this

alternative and some others to follow becomes dependent

upon the required runway length and strength.

Assume the development of an advanced long range

bomber which is capable of operating from airfields with

8000 feet or more of hard surface runway. Then there

would be 101 USAF bases available to bed down these aircraft.

Again, using the same parameters as before and the B matrix for all AF bases with runways over 8000 feet, the problem can be solved for comparison. The B matrix for this case is $\begin{bmatrix} 57 & 19 & 19 & 3 & 2 & 1 \end{bmatrix}$ and the resulting force survival matrix is given by:

$$BA = F \begin{bmatrix} 742 \\ 394 \\ 143 \\ 24 \\ 0 \end{bmatrix}$$

If Threat III is used for comparison, the model shows that 143 aircraft could survive. This represents a gain of 28 aircraft over the "all SAC bases" alternative. If the threat is less severe, the gain is even more significant. However, if it is more severe, there is no gain in force survival. This is due to the fact that there were no additional AF bases in zones 5 and 6 (see Figure 2).

One advantage to using all USAF bases is that construction costs would be minimal, consisting chiefly of alert facilities. Some additional communications links would probably have to be established.

Another advantage is that all aircraft on alert with nuclear weapons would be based on military installations. This is an advantage when compared with alternatives considering the use of civilian fields.

All Military Bases

Another option open to U.S. strategists is to utilize all military installations which have adequate airstrips. Using the 8000 foot assumption of the previous alternatives there are now 50 additional bases (Army, Navy, and Coast Guard) at which an advanced bomber could be stationed. However, examination of the locations of these additional 50 bases reveals that very few are located within zones 4,5, or 6. This results in a very minor increase in the number of bombers escaping Threat III. If the threat is even more severe there is essentially no increase in force survival with this alternative.

The advantages are similar to those of the all Air Force alternative. Construction requirements would be minimal, existing communications could be improved, and nuclear weapons would be confined to military installations.

Cost is not a large factor in either case and primary consideration would have to be the severity of the threat and the size force which must survive.

All Civilian plus All Military Fields

In an effort to make even more runways available, and thus potentially increase the number of aircraft escaping a particular threat, utilization of all civilian fields can be considered. With this alternative, 158 additional airstrips of over 8000 feet are available. Twenty-two of these are in zone 3, ten in zone 4, five in zone 5,

and none in zone 6.

This means that if Threat III is used for comparison once again, an additional 246 aircraft could survive, increasing total force survival to approximately 389.

Note here that, given the arbitrary selection of Threat III, total force survival is approaching the total number of aircraft in the bomber force. Assuming for this discussion that approximately 50 per cent of the total force is on alert at any given time, it is apparent that not all of the 37 civilian fields in the interior zones need be used. In selecting which ones to eliminate, consideration could be given to their proximity to missile sites, other military installations, large industrial or metropolitan areas, or any other areas which might be considered high value targets to the enemy. The basing of bombers in these areas would only serve to increase the priority the enemy would place on destroying such lucrative targets.

Many of the advantages of previous alternatives become the disadvantages of this one. Costs of construction of facilities and communications networks would be higher. There would be political and social considerations if nuclear weapons were to be based on civilian fields. Security of nuclear weapons would present more of a problem.

If the threat to survival becomes severe enough to consider using civilian fields, then these costs will have

to be weighed against the costs of other means of increas-
ing force survival. Some of these methods will be dis-
cussed later in this chapter.

Shell Game

Associated with the possibility of using all military
and civilian bases is the potential of using a shell
game. If there are more bases available than would be
required to get total force survival of 100 per cent (or
any desired level), then a plan can be devised for
continually changing the alert bed down. Aircraft could
be relocated monthly, weekly, or even daily to complicate
the enemy's targeting problem.

If the number of bases used in a shell game is more
than the enemy can realistically target with SLBM's,
survival can be calculated using the model developed in
Chapter IV and the probability of each base being targeted,
to yield an expected value for force survival. In this
case it would be possible to utilize bases in zones near
the coast, since there is some probability of each base
not being targeted.

Cost considerations of the "shell game" alternative
are similar to the "all civilian plus all military fields"
alternative, but would be even higher since more bases
would have to be used.

Launch Interval

As long as there are fewer submarines than bases

to be targeted, the interval between missile launches from
a single submarine is a significant figure. Assuming an
SLBM launch interval of one minute, aircraft located at
a base not targeted on the first salvo have an additional
one minute of reaction time (Ref 13:127). A bomber launch
interval of fifteen seconds would mean an additional
four safe aircraft in this case, and with shorter launch
intervals even more could survive.

Targeting Strategy

In addition to these intervals, bomber force survival
is dependent on the enemy targeting strategy, i.e.,
whether they target the most distant bases or the nearest
bases with the first salvo. Figure 16 will help to
illustrate this concept.
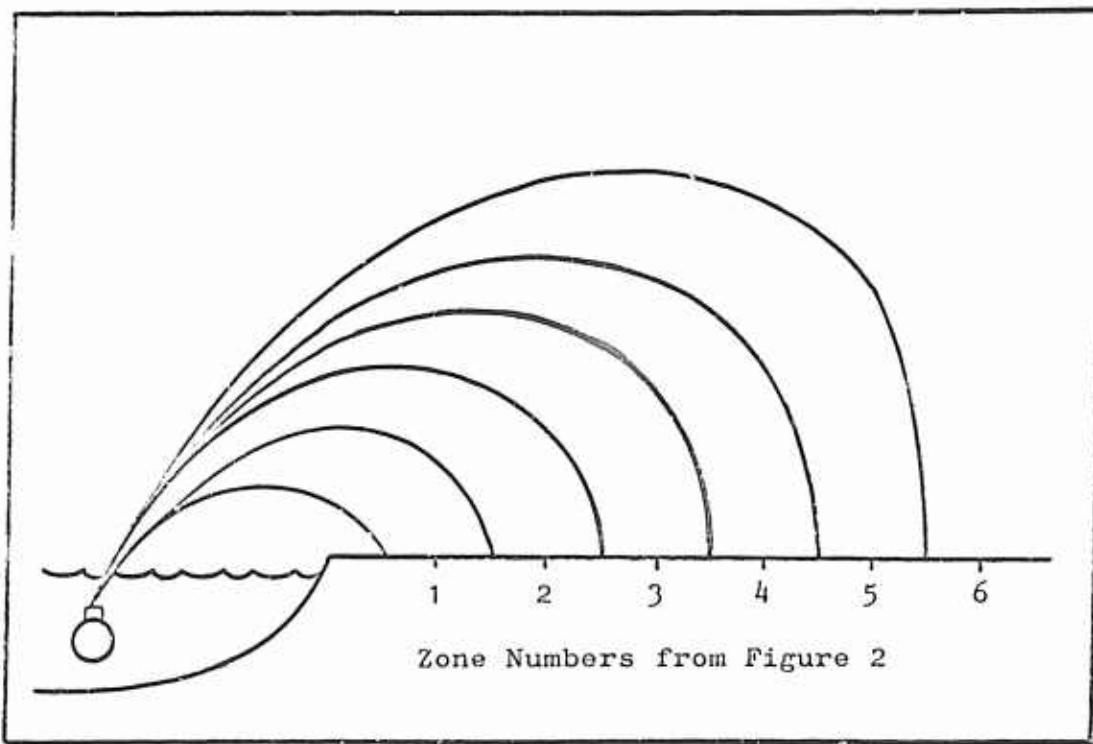
Figure 16. SLBM Targeting Strategy

If bases in the most distant zone are targeted first, other zones nearer the coastlines would be provided additional warning time which might allow more aircraft to escape. Conversely, when the bases in the near zones are targeted first, the more distant bases would gain the additional time.

However, the formulation presented in this paper is deterministic and based on the assumption that all bases are targeted on the first salvo. This "worst case" approach does not include additional time based on firing interval for SLBM's, and it is not stochastic in the sense that it does not take into account the probability of a base not being targeted. Further, it is based on the assumption that the enemy would not choose either extreme targeting strategy of attacking the most distant or the nearest bases first, but rather one in which bases in all zones are targeted uniformly on the first salvo.

Grid of Austere Bases

Another alternative to be discussed in some detail is the possibility of constructing a system of runways to complement or completely replace the existing network of bomber bases. A simplified approach to this is to use an area relatively insensitive to the SLBM threat, such as the 1000 nautical mile contour line (see Figure 2). Within this area a grid of austere bases could be constructed with the minimum facilities necessary to support alert aircraft and crews. The distance between bases in this

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grid is governed by several considerations. The most obvious is the number of bases required, since the area is defined.

Weapon size and type of attack is another parameter determining the distance between bases. Single one or two megaton weapons do not present much problem from this standpoint, even when the CEP is considered, if the distance between bases is in excess of twenty miles. Clusters of smaller weapons delivered by MRV's could give larger footprints, but still would not make the distance critical. The MIRV complicates the problem since this type of missile has several warheads which can be independently targeted. The number of bases targeted by one missile may be three or more and thus many more bases would be necessary to escape the first salvo. Unclassified information on this type of delivery is not readily available, but it can be assumed that there are limits on the length and breadth of the area within which independent targeting can be accomplished with one missile trajectory.

The approximate size of the 1000 nautical mile contour is 200 nm x 200 nm. If the distance between bases is X nautical miles then the number of bases in the grid (G) would be given by:

$$\left(\frac{200}{X} + 1\right) \left(\frac{200}{X} + 1\right) = G$$

After the required number of bases is determined with the assistance of the survival equation, solving for X will give the distance between bases.

Construction of this grid would be an expensive venture, but a cost analysis should be run to compare it with other alternatives. The comparison will involve the numerous problems ever present in this type of analysis, i.e., comparing dollar costs with social costs, and determination of how much is enough when considering deterrence and survival (see Ref 20 for a discussion of these topics).

It may be that when all things are considered, the cost of building austere bases in the sparsely populated area of zone 6 is reasonable. One point which should not be overlooked, however, is that although zone 6 may be relatively insensitive to the current and projected " most severe threat " (i.e., SLBM), this area could become vulnerable to other types of attack. If the fractional orbital bombardment system (FOBS) is developed, it may allow even less time for reaction. If this is the case, grouping all bomber bases in such a relatively small area as zone 6 could be disastrous.

Submarine Detection

One means of increasing the number of aircraft surviving under the various alternatives is to force the enemy submarines to maintain a greater distance from the U.S. coastline. This capability would cause an increase in the missile time of flight to every zone and survival could be calculated with the equation of Chapter IV.

Another potential means of increasing the survival

number is to increase the number of bases within the interior zones. The construction of new bases within the presently outlined zones has already be discussed. However, with improved anti-submarine detection systems other improvements can result. Potential improvement arises out of the ability of U.S. forces to keep the enemy submarines out of the Gulf of Mexico, even if the 100 nautical mile launch distance from other coastlines is maintained. This would provide a detection line starting at the southern tip of Florida, passing the western end of Cuba, and extending across the Gulf to the northern tip of the Yucatan peninsula. Figure 17 shows the added territory in the interior zones when this is considered. Note the substantial increase in area of zones 5 and 6. With this increased area, more bases can be utilized in these regions, thus increasing the number of surviving aircraft under the various basing alternatives.

Canadian Land

Another possible alteration to the contour chart (Figure 2) concerns the possible utilization of land in south-central Canada due north of zone 6. This would provide additional land in the most insensitive zone. As there are no existing U.S. bases in this region, utilization of this land would require funding for construction of bases, austere or full support, before any advantage would be realized. The most likely option would be to build several austere bases to complement the "grid
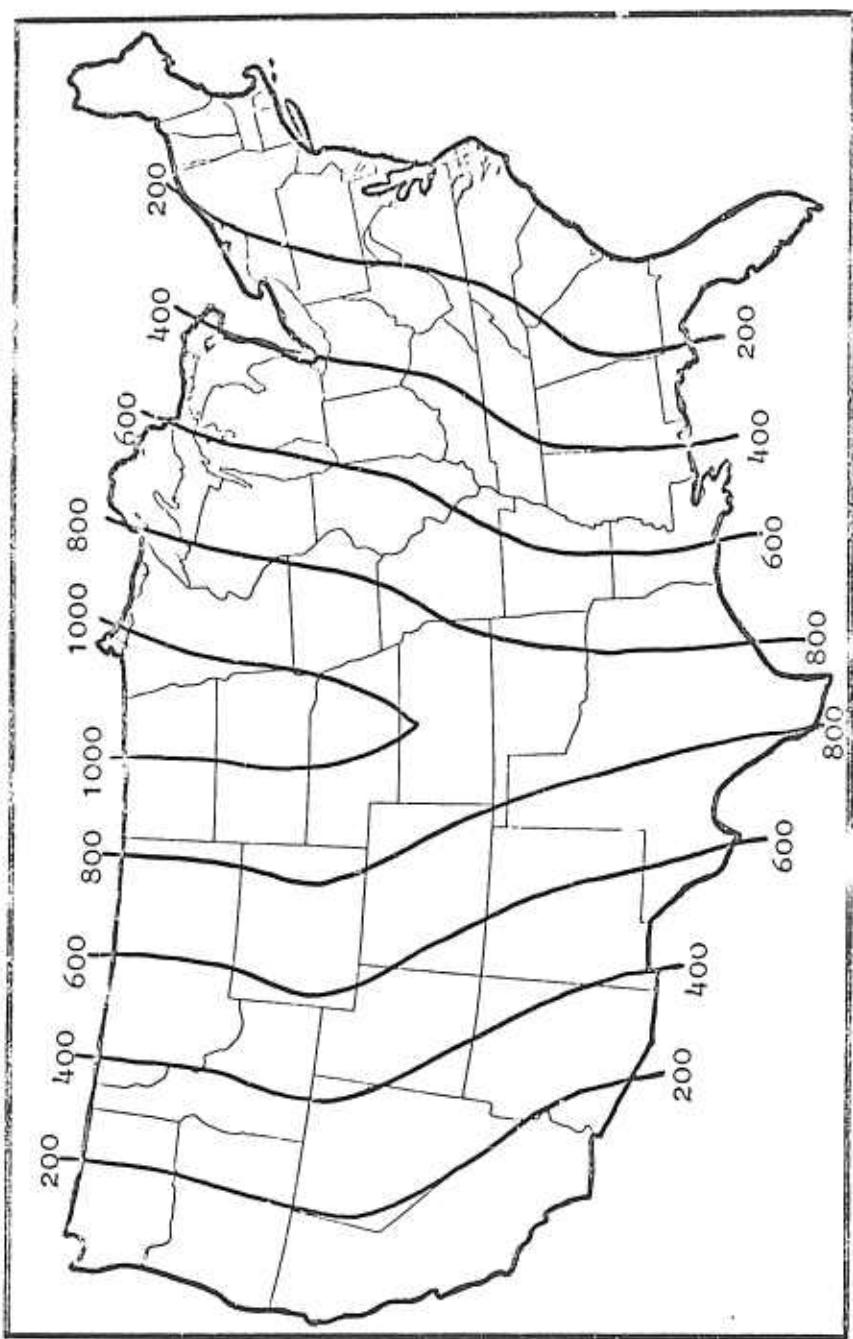
Figure 17. 200 Nautical Mile Contours with Gulf of Mexico Blockade

of austere bases" alternative or perhaps any of the alternatives for increased force survival.

The political ramifications which might arise, due to the basing of nuclear weapons on Canadian soil, may allow only tankers to be based in this area. A study of the tanker basing problem should not overlook the potential gain from such a diplomatic maneuver.

Runway Requirement

Regardless which of the preceding alternatives is used, there are several other means of improving force survival. One of these methods, mentioned earlier as an assumption, is designing a long range bomber capable of operating from shorter runways. Appendix B illustrates the additional bases available when the runway requirement becomes less.

In addition to more runways being available, some of the very long runways could be utilized so as to double the number of aircraft surviving at any given base. This could be accomplished by building the alert facilities at the center of the runway and simultaneously launching in both directions. If this length is marginal for safe take-off, extensions could be built on both sides at the center of the runway. These extensions could be built at a small angle to the runway orientation to allow for rolling take-off. This might appear something like Figure 18, with an underground alert facility below the runway and alert aircraft parked on both sides.
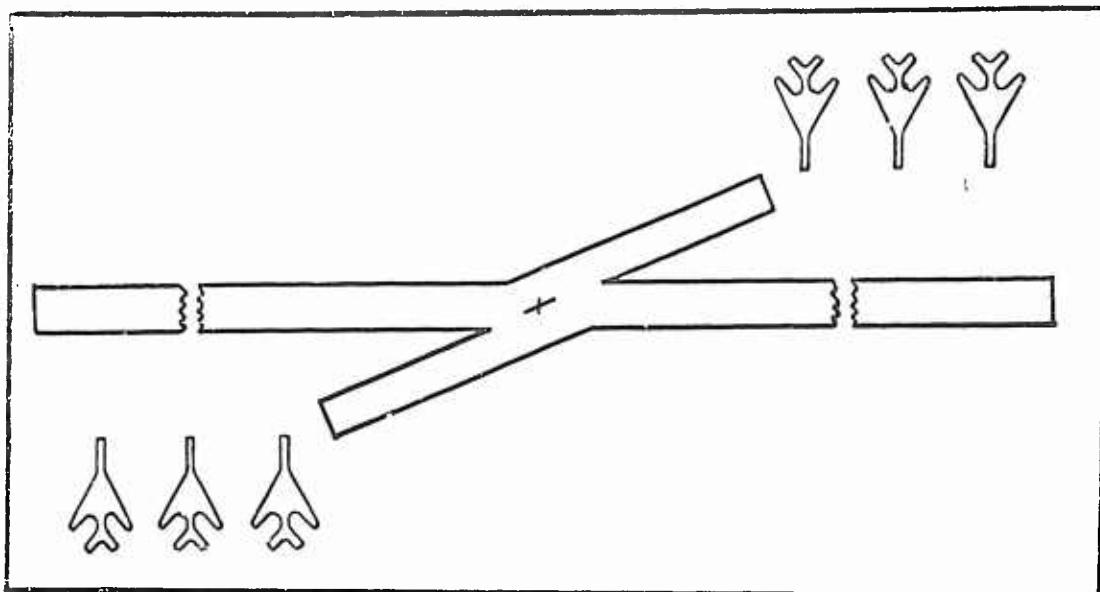
Figure 18. Runway Extension Diagram

A more costly alternative to double the number of
aircraft taking off in any given interval of time is to
build a parallel runway. This might be desirable where
there are existing runways less than 10,000 feet long.
At these bases construction of the additional runway
might cost less than the extensions and the other
modifications just discussed.

Airborne Alert

A tried and proven method of insuring survivability
against the prelaunch threat is airborne alert. This
capability has been thoroughly evaluated, operationally
tested, and can be mounted anytime it is required in
response to proper authority. While some of the SAC
bomber-tanker force in the U.S. and overseas is on ground
alert at all times, all SAC heavy-bomber units are capable
of maintaining airborne alert. Although more costly than

78

ground alert, it can be reactivated for an increased

alert posture, a show of force, or an interim measure

to insure prelaunch survival against some unforeseen

threat (Ref 66).

Takeoff Interval

The interval at which bombers are launched to escape

a surprize attack has a large effect on force survival.

An aircraft closely following another on takeoff roll is

affected by the turbulence caused by the leading plane.

In normal weather conditions (light crosswinds) an inter-

val of 15 seconds between similar aircraft and 30 seconds

between dissimilar aircraft is considered to be adequate

for safe operations (Ref 74:26). It is obvious from the

survival equation that if this interval is halved, the

number of aircraft taking off during any given period

is doubled. However, as the interval is shortened the

danger of aircraft loss due to an accident is increased.

A tradeoff analysis between the additional aircraft

surviving an attack from enemy SLBM's and the possibility

of an accident causing aircraft loss due to shortening

the takeoff interval can be made. With this type of

analysis, a decision could be made to determine the level

risk acceptable in attempting to increase force survival

by reducing the takeoff interval. Figure 19 (which is

hypothetical) illustrates this tradeoff. Further analysis

of this tradeoff would have to include the possibility of

an accident on takeoff rendering the runway unusable to
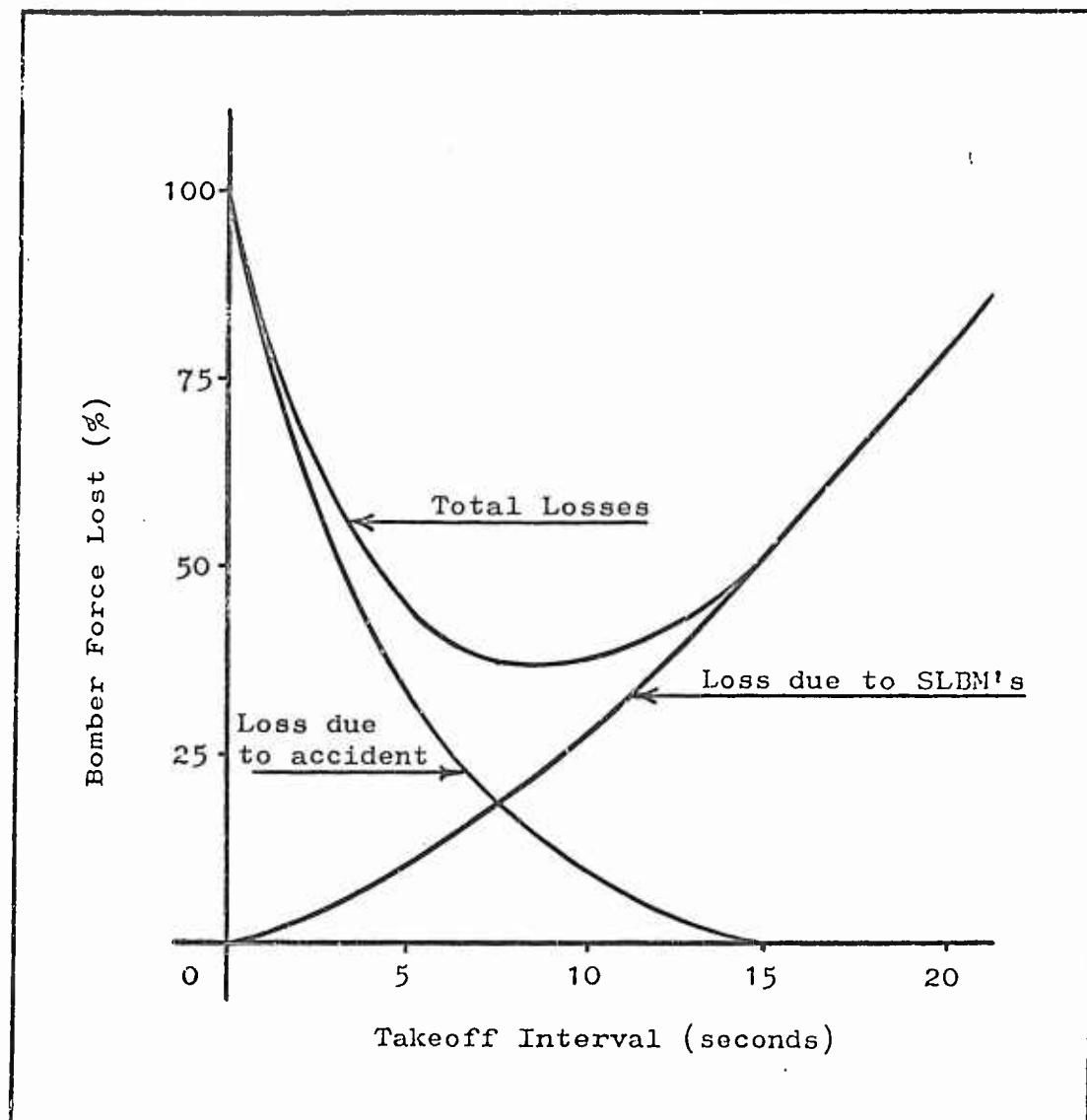
Figure 19. Effect of Takeoff Interval on Aircraft Losses

other aircraft for takeoff and escape.

Bomb Load

Another tradeoff concerning the survival of long

range bombers is the effect of aircraft weight on per-

formance. It may be that a lighter aircraft, whether

determined by design or by bomb load, could have better

escape characteristics than a heavier one. This might
allow shorter takeoff intervals and faster fly out times.
Also it may be desirable to get more planes airborne with
lighter bomb loads (rather than less planes with heavier
bomb loads) due to the nature of their intended targets
and other survival problems enroute and during penetra-
tion of enemy air defenses. Solution of this type prob-
lem would require classified information and is beyond
the scope of this paper. It is, however, worth noting
the type of analysis which might be used to make this
decision.

Tables XIV and XV summarize the basing alternatives
and survival improvement techniques discussed in this
chapter and elsewhere in the report.

Table XIV

Summary of Basing Alternatives

ALTERNATIVE	EFFECT
All SAC Bases	48 bases in the six zones, $B = \begin{bmatrix} 21 & 9 & 13 & 2 & 2 & 1 \end{bmatrix}$, survival against Threat III = 115.
All USAF Bases	101 bases with 8000 feet of runway (or more) distributed $B = \begin{bmatrix} 57 & 19 & 19 & 3 & 2 & 1 \end{bmatrix}$, survival against Threat III = 143.
All Military Bases	50 additional bases giving only minor increase in survival for more severe threats.
All Civilian Plus All Military Fields	158 additional fields with 8000 feet or more hard surface runway, 22 in Zone 3, 10 in Zone 4, 5 in Zone 5, none in Zone 6; Total force survival against Threat III = 389.
Shell Game	Continual change of bomber bed-down to confuse enemy targeting.
Grid of Austere Bases	Construction of bases in the most insensitive zone(s).
Gulf of Mexico Blockade ...	Force enemy submarines to stay further from southern shore of U.S. to increase area of the interior zones.
Use of Canadian Soil	Increase the area of the most interior zones, possibly for basing tankers.

Table XV

Summary of Survival Improvement Techniques

TECHNIQUE	EFFECT
Improve Aircraft Design:	
Shorten Takeoff Roll	More bases available for bomber operations.
Increase Hardness ....,.	Shorten escape distance.
Acceleration & Speed	Faster fly out time.
Shorten Critical Time (T) ... Improve Detection System Improve Warning System Improve Crew Reaction Improve Aircraft Reaction Faster Fly Out Time	Allows more time for aircraft to escape for any given threat, i.e., (M - T) is larger.
Launch in Both Directions ...	Doubles the number of aircraft surviving.
Parallel Runways	Two runways doubles the number of aircraft surviving.
Takeoff Interval Tradeoff ...	Shorter interval increases prelaunch survival, but also increases risk of accidents.
Aircraft Weight Tradeoff	Lighter aircraft (by design or less bomb load) gives shorter takeoff roll and faster fly out time; may be dependent on target objectives and enemy defenses.
Airborne Alert	Insensitive to the SLBM threat.

VI. Conclusions and Recommendations

> When there is mutual fear, men think
> twice before they make aggression upon
> one another.
>> Hermocrates of Syracuse:
>> to the Sicilian envoys
>> at Gela, 424 B.C.
>> (Ref 29:87)

Survival in this world, where nuclear warfare could destroy the current civilization, depends on the policy of deterrence between the nuclear powers. As long as the United States policy of "realistic deterrence" continues to be supported by the triad concept, there will be a requirement for each element of the triad to maintain the capability to survive a surprise attack.

In order for the manned bomber to remain a viable part of the triad, it must be able to survive an attack from the most severe enemy threat in each of its operational modes, i.e., prelaunch, enroute, and penetration.

Prelaunch survival might be accomplished by an anti-ballistic missile (ABM) system, but since there is none in existence today to support this theory, the question arises: can the manned bomber survive a prelaunch attack without the aid of an ABM system? The strategic bomber would have to rely on reaction time alone, based on detection and warning of impending attack, crew reaction, and aircraft design characteristics.

The severity of the threat, with regards to reaction time, is a key parameter needed for solution of the

problem. Estimates of enemy capabilities vary considerably, but there is general agreement that the most severe threat to the prelaunch survival of manned bombers based in the United States is the sea-launched ballistic missile. Exact information on the performance of known and projected weapon systems is classified. For this reason, simulated threats covering a wide range of possibilities were postulated for use in the analysis of this problem (Figure 1).

The model developed in Chapter IV to aid in the analysis of various survival improvement techniques is relatively uncomplicated. This allows hand calculation and requires no computer assistance. The validity of the answers in terms of total bomber force survival depend on the accuracy of the inputs. Holding certain variables constant facilitates accurate comparison of alternatives and allows a sensitivity analysis of elements of the survival equation.

The analyses of several basing concepts and other means of improving prelaunch survival of a manned bomber force in Chapter V indicate the wide range of possibilities to be considered. These analyses are limited by the lack of cost data available. Thus, a first recommendation for further study is a cost effectiveness analysis of these proposals and a comparison between the best of these methods (or others subsequently developed) and an ABM system.

Another topic which merits further investigation
is the effect of SLBM launch interval on bomber survival.
Appendix C suggests one possible approach to this problem
using the model developed in this study.

The survival of tanker aircraft for aerial refueling
of long range bombers has not been covered in this paper.
There are several tanker studies in existence and some
computer models are available to aid in the analysis of
this problem. Further study should include the combined
problems of tanker and bomber survival, since they are
interdependent.

Additional unclassified studies in these areas should
help provide the basis for continued analysis of the
problem at any level. One is never sure that all of the
alternatives have been considered, and new technology will
increase the possibilities for tomorrow.

Bibliography

1. Ackoff, Russell L. and Maurice W. Sasieni.
    Fundamentals of Operations Research. New York:
    John Wiley & Sons, Inc., 1968.

2. Aerospace International. "Tables of Major Nuclear
    Delivery Vehicles, 1970", Vol. 6, No. 6 (November-
    December 1970). Tables for the U.S. and U.S.S.R.
    were extracted from The Military Balance 1970-1971.
    London, England: The Institute for Strategic Studies,
    1970.

3. Alternative U.S. Strategies and America's Future.
    Philadelphia, Pennsylvania: University of Pennsyl-
    vania, 1964.

4. Atkinson, George W. and LCDR. H.G. Laursen, USNR.
    Nomographs for Determining the Relationships Between
    Pressure, Range, Altitude, and Yield in the Shock
    Front Resulting From a Nuclear Detonation.
    Albuquerque, New Mexico: U.S. Naval Weapons Eval-
    uation Facility, 31 January 1965.

5. B - 1. U.S./Air Force/Fact Sheet 70-8. Washington,
    D.C.: Secretary of the Air Force, Office of Infor-
    mation, August 1970.

6. Bacalis, Maj.Gen. Paul N., USAF, DCS/Plans, Strategic
    Air Command. Description of the B-1 to American
    Ordnance Association in Orlando, Florida. Air Force
    Policy Letter for Commanders. Washington, D.C.:
    Secretary of the Air Force, 15 January 1971.

7. Baldwin, Hanson W. Strategy for Tomorrow. New York:
    Harper & Row, Publishers, 1970.

8. Barrett, Raymond J. Air Force Policy Letter for
    Commanders. Washington, D.C.: Secretary of the
    Air Force, 1 June 1970.

9. Bliss, Gilbert Ames. Mathematics for Exterior
    Ballistics. New York: John Wiley & Sons, Inc., 1944.

10. Bracken, Jerome and Garth P. McCormick. Selected
    Applications of Nonlinear Programming. New York:
    John Wiley & Sons, Inc., 1968.

11. Bracken, Jerome and James T. McGill. A Convex
    Programming Model for Resource Allocation with
    Time-Dependent Objectives: SLBM Attack of Bomber
    Bases. Arlington, Virginia: Institute for
    Defense Analysis, Program Analysis Division, 1970.

12. Brode, H.L. Height of Burst Effects at High Overpressures. RM-6301-DASA (DASA 2506). Santa Monica, California: The Rand Corporation, July 1970.

13. Brown, Neville. "Deterrence From The Sea", New Scientist. Vol. 46, No. 697 (16 April 1970).

14. Buchan, Alastair (ed.). A World of Nuclear Powers? Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1966.

15. Campen, C.F.,Jr. et al.(eds.). Handbook of Geophysics for Air Force Designers. Geophysics Research Directorate, Air Force Cambridge Research Center, USAF, 1957.

16. Chayes, Abram and Jerome B. Weisner (eds.). ABM: An Evaluation of the Decision to Deploy an Antiballistic Missile System. New York: Harper & Row, Publishers, Inc., 1969.

17. COG Model, The: A General Introduction. Arlington, Va.: LAMBDA Corporation, 4 February 1971.

18. Cordes, Brig. Gen. Harry N. "The Strategic Threat" Air Force Magazine. Vol. 54, No. 7 (July 1971).

19. "Defense Highlights: Review and Opinion" Ordnance. Vol. LV, No. 301 (July-August 1970).

20. Enthoven, Alain C. and K. Wayne Smith. How Much Is Enough? Shaping the Defense Program, 1961-1969. New York: Harper & Row, Publishers, Inc., 1971.

21. Foster, John S. "Russia vs. U.S. - Coming Crisis in Arms" U.S. News & World Report. Vol. LXIX, No. 22 (30 November 1970).

22. ------. address at Air Force Association meeting 23 September 1970 in Washington, D.C. Air Force Policy Letter for Commanders. Washington, D.C.: Secretary of the Air Force, 1 October 1970.

23. ------. address at American Newspaper Publishers Association meeting in New York on 23 April 1970, Air Force Policy Letter for Commanders. Washington, D.C.: Secretary of the Air Force, 1 May 1970.

24. Gantz, Kenneth F. The United States Air Force Report on the Ballistic Missile: Its Technology, Logistics and Strategy. Garden City, New York: Doubleday and Company, Inc., 1958

25. Gass, Saul I. Linear Programming. New York: McGraw-Hill Book Company, 1964.

26. Glasstone, Samual (ed.). The Effects of Nuclear Weapons. United States Atomic Energy Commission, June 1957 and April 1962 (rev. ed.).

27. Hadley, G. Linear Algebra. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc., 1961.

28. Haywood, O.G., Jr. "Military Decision and Game Theory" Journal of the Operations Research Society of America. Vol. 2, No. 4 (November 1954).

29. Heinl, Robert Debs, Jr. Dictionary of Military and Naval Quotations. Annapolis, Maryland: United States Naval Institute, 1966.

30. Herrick, Robert Waring. Soviet Naval Strategy. Annapolis, Maryland: United States Naval Institute, 1968.

31. Hobbs, Norman P., Garabed Zartarian, John P Walsh and Kaman Avidyne. A Digital Computer Program for Calculating the Blast Response of Aircraft to Nuclear Explosions. Volume 1, Program Description, Report No. AFWL-TR-70-140. Kirtland AFB, New Mexico: Air Force Weapons Laboratory (AFSC), April 1971.

32. Holloway, Gen. Bruce K. "The Strategic Frontier" Ordnance. Vol. 55, No. 306 (May-June 1971).

33. Holst, Johan J. and William Schneider, Jr. (eds.) Why ABM?: Policy Issues in the Missile Controversy. New York: Pergamon Press, 1969.

34. IFR Supplement: United States, DOD Flight Information Publication (Enroute). St. Louis, Missouri: The Aeronautical Chart and Information Center, USAF, 24 June 1971.

35. Kintner, William R. and Harriet Fast Scott. The Nuclear Revolution in Soviet Military Affairs. Norman, Oklahoma: University of Oklahoma Press, 1968.

36. Laird, Melvin R. Fiscal Year 1972-76 Defense Program and the 1972 Defense Budget. Washington, D.C.: U.S. Government Printing Office, 9 March 1971.

37. ------. statement to Disarmament Subcommittee of the Senate Foreign Relations Committee, Air Force Policy Letter for Commanders. Washington, D.C.: Secretary of the Air Force, 1 June 1970.

38. Lapp, Ralph E. Arms Beyond Doubt: The Tyranny of
     Weapons Technology. New York: Cowles Book Company,
     Inc., 1970.

39. -----. The Weapons Culture. New York: W.W. Norton
     and Company, Inc., 1968.

40. Loosbrock, John F. "The B-1 Is A Must" Air Force
     Magazine. Vol. 54, No. 6 (June 1971).

41. McKee, Gen. Seth J. "Against Air Attack" Ordnance.
     Vol. 55, No. 303 (November-December 1970).

42. McNamara, Robert S. The Essence of Security.
     New York: Harper & Row, Publishers, Inc., 1968.

43. Martin, Lt.Gen. Glen W. Air Force Policy Letter for
     Commanders. Washington, D.C.: Secretary of the Air
     Force, 15 May 1970.

44. Martin, Thomas L., Jr. and Donald C. Latham.
     Strategy for Survival. Tuscon, Arizona: The
     University of Arizona Press, 1963.

45. Meyer, Gen. John C. "The Soviet Threat" Ordnance.
     Vol.55, No. 303 (November-December 1970).

46. -----. "Why We Need the Triad" Air Force Policy
     Letter for Commanders. Washington, D.C.: Secretary
     of the Air Force, 15 May 1971.

47. Missile Effectiveness Calculator. Syracuse, New
     York: General Electric, Special Information Products
     Department, Defense Electronics Division, 1965.

48. Morris, William T. The Analysis of Management
     Decisions. Homewood, Illinois: Richard D. Irwin,
     Inc., 1964.

49. -----. Management Science: A Bayesian Introduction.
     Englewood Cliffs, New Jersey: Prentice-Hall, Inc.,
     1968.

50. Murphy, Charles J. V. "The Desperate Drive to Cut
     Defense Spending" Fortune. (January 1964).

51. Nelson, Maj.Gen. Douglas T. "Why We Need the B-1"
     remarks by the B-1 system project officer to the
     American Institute of Aeronautics and Astronautics,
     Woodbury, Long Island, 10 November 1970.

52. -----. "The Accent is on Flying" Air Force Magazine.
     Vol. 54, No. 6 (June 1971).

53. Nixon, Richard. U.S. Foreign Policy for the 1970's: A New Strategy for Peace. A Report to the Congress, 18 February 1970.

54. Nuclear Bomb Effects Computer. The Lovelace Foundation, under contract to The Division of Biology and Medicine, U.S. Atomic Energy Commission, 1962.

55. Nuclear Weapons Effects: Comprehensive Report. Surveys of Soviet-Bloc Scientific and Technical Literature, ATD Report P-65-1. Aerospace Technology Division, Library of Congress, 14 January 1965.

56. Pronin, L.N. Ballistic Missiles. Source: trans. from "Ballisticheskiye Rakety" Izd-vo Ministerstva Oborony SSSR, Moscow, 1969, pp 1-111. Wright-Patterson AFB, Ohio: Foreign Technology Division, 24 April 1970.

57. Quade, E.S. and W.I. Boucher (eds.). Systems Analysis and Policy Planning: Applications in Defense. New York: Elsevir Publishing Company, Inc., 1968.

58. Richmond, Samuel B. Operations Research for Management Decisions. New York: The Ronald Press Company, 1968.

59. Ryan, Gen. John D. "B-1: A Wise Investment for National Defense" Air Force Policy Letter for Commanders. Washington, D.C.: Secretary of the Air Force, 1 July 1971.

60. -----. "The B-1: A Future Mainstay of Deterrence" remarks by the Air Force Chief of Staff at the 13th Annual Aerospace Luncheon of the Los Angeles Area Chamber of Commerce, Los Angeles, California, 30 October 1970.

61. "SAC Satellite Base Expansion Reduced" Air Force Times. Vol. 32 No. 2 (18 August 1971).

62. Schnapper, M.B. (ed.). National Priorities: Military, Economic, and Social. Washington, D.C.: Public Affairs Press, 1969.

63. Seamans, Robert C. Jr. Remarks by the Secretary of the Air Force at Air Force Association Convention, Washington, D.C., 23 September 1970.

64. -----. Air Force Policy Letter for Commanders. Washington, D.C.: Secretary of the Air Force, 15 January 1970.

65. "Sea Watch Established" Air Force Times. Vol. 32, No. 5 (8 September 1971).

66. Strategic Air Command. U.S./Air Force/Fact Sheet 71-6. Washington, D.C.: Secretary of the Air Force, Office of Information, June 1971.

67. Ulsamer, Edgar. "The U.S.S.R. is Headed Toward Technological Superiority", an interview with Dr. John S. Foster, Jr. Air Force Magazine. Vol. 54, No. 8 (August 1971).

68. -----. "The Accent is on Flying" Air Force Magazine. Vol. 54, No. 6 (June 1971).

69. VFR Supplement: United States, DOD Flight Information Publication (Enroute). St. Louis, Missouri: The Aeronautical Chart and Information Center, USAF, 4 February 1971.

70. Wagner, Harvey M. Principles of Operations Research: With Applications to Management Decisions. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969.

71. Ward, Dudley C., John U. Abele, and Arturo V. Serrano. Development of Computerized Solutions of Safe Escape Problems in Nuclear Weapons Delivery. Technical Report ASD-TR-68-4. Dayton, Ohio: Technology Incorporated, February 1968.

72. Weiss, George. "Strategic Deterrence: Rationale, Negotiations, Threat, and Status" Armed Forces Journal. Vol. 108, No. 19 (7 June 1971).

73. -----. "Will the B-1 Suffer the Fate of the SST?" Armed Forces Journal. Vol. 108, No. 18 (17 May 1971).

74. -----. "Strategic Deterrent Affected by ASW" Armed Forces Journal. Vol. 108, No. 17 (3 May 1971).

75. -----. "The F-111: The Swing-Wing May Surprise You Yet" Armed Forces Journal. Vol. 108, No. 22 (19 July 1971).

76. Witze, Claude, "Threats: At Home and Abroad" Air Force Magazine. Vol. 54, No. 6 (June 1971).

77. Zlotnick, Jack and John D. Matheson. Optimal Aircraft Deployment for the SLBM Threat. Strategic Branch Note 70-3. Falls Church, Virginia: Analytic Services Incorporated (ANSER), May 1970.

Appendix A

General Principles of Nuclear Explosions

This appendix is presented as a supplement to the weapons effects discussion in Chapter IV to supply the reader with background information pertinent to this paper. The entire appendix was extracted from selected portions of The Effects of Nuclear Weapons (Ref 26). For a more in depth study of weapon effects involving other types of bursts and the effects of burst other than blast effects, the reader should consult the source document.

In general, an explosion is the release of a large amount of energy in a short interval of time within a limited space. The liberation of this energy is accompanied by a considerable increase in temperature, so that the products of the explosion become extremely hot gasses. These gasses, at very high temperature and pressure, move outward rapidly. In doing so, they push away the surrounding medium--air, water, or earth--with great force, thus causing the destructive (blast or shock) effects of the explosion.

The atomic (nuclear) blast is similar to the more conventional type of bomb in so far as its destructive action is due mainly to blast or shock. However, apart from the fact that nuclear bombs can be many thousands of times more powerful than the largest TNT bombs, there are other more basic differences. First, a fairly large

proportion of the energy in a nuclear explosion is emit-
ted in the form of light and heat, which is generally
referred to as "thermal radiation". Second, the explosion
is accompanied by highly penetrating and harmful, but
invisible, rays called the "initial nuclear radiation".
Finally, the substances remaining after a nuclear explo-
sion are radioactive and emit similar radiations over
an extended period of time. This phenomenon is known
as the "residual nuclear radiation".

The power of a nuclear weapon is expressed in terms
of its total energy release (yield) compared with the
energy liberated by TNT when it explodes. Thus, a one
kiloton (1 KT) nuclear bomb is one which produces the same
amount of energy as the explosion of 1000 tons of TNT.
A one megaton (1 MT) weapon would have the energy equiv-
alent of one million tons of TNT. The nuclear bombs drop-
ped over Japan in 1945 were approximately 20 KT in yield.

In the explosion of a conventional bomb, nearly all
the energy released appears immediately as kinetic energy.
Almost the whole of this is then converted into blast and
shock. In a nuclear explosion only about 85% of the
energy released is in the form of kinetic energy, and
only a part of this is utilized to produce blast and
shock. The other 15% appears as heat and light rays.
The distribution of energy in a typical nuclear air
burst is shown in Figure 20.

The immediate phenomena associated with a nuclear

THERMAL
RADIATION

35%

RESIDUAL
RADIATION

10%

INITIAL
RADIATION

5%

BLAST AND SHOCK

50%
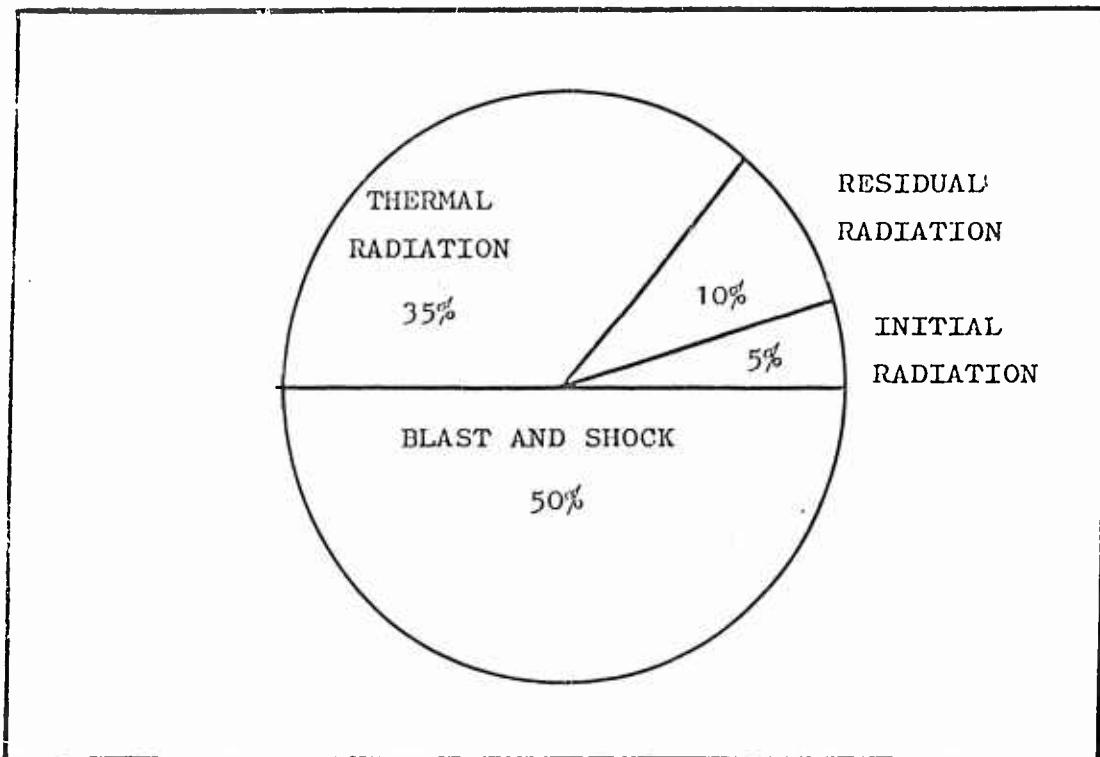
Figure 20. Distribution of Energy in a Nuclear Air Burst

explosion vary with the location of the point of burst
in relation to the surface of the earth. For descriptive
purposes, four types of bursts are distinguished: (1) air
burst; (2) underwater burst; (3) underground burst; and
(4) surface burst.

Almost at the instant of a nuclear explosion there
is formed an intensely hot and luminous mass, roughly
spherical in shape, called the "ball of fire" or
"fireball". An air burst is defined as one in which
the bomb is exploded in the air at such a height that
the fireball (at maximum brilliance) does not touch
the surface of the earth.

A surface burst is regarded as one which occurs

either at the actual surface of the land or water, or at any height above the surface such that the fireball touches the land or water.

If a nuclear explosion occurs such that its center is beneath the ground or under the surface of the water, the situation is described as an underground burst or an underwater burst respectively.

Further description of nuclear explosions will be limited to air burst phenomena only. The reason for this is made evident in Chapter IV. It is sufficient here to note that the blast effects of an air burst at optimal height have a more far reaching effect on the critical parameters of this study.

Chronological Development of an Air Burst

Immediately following the detonation of a nuclear bomb in the air, the fireball is formed. Due to its extremely high temperature, it emits thermal radiation capable of causing skin burns and starting fires at a considerable distance. Very soon after the explosion a destructive shock (or blast) wave develops in the air and moves away from the fireball (Figure 21).

At the times indicated in Figure 21, the ball of fire has almost reached its maximum size. The shock front is seen to be well ahead of the fireball--about 750 feet for the 20 KT burst and a little over one-half mile for the 1 MT detonation.

When the primary shock wave from the explosion

strikes the ground, another shock wave is produced by reflection. At a certain distance from ground zero, which depends upon the height of burst and energy of the bomb, the primary and secondary (reflected) shock fronts fuse near the ground to form a single, reinforced Mach front (or stem). The time and distance at which the Mach effect commences for a typical air burst are as shown in Table XVI.

Table XVI

Time and Distance for Mach Effect

Explosion Yield	Time After Detonation	Distance From Ground Zero
20 KT	1.25 sec	0.35 miles
1 MT	4.60 sec	1.30 miles

The overpressure at the earth's surface is then 16 pounds per square inch (psi). The commencement of the Mach effect is illustrated in Figure 22.

As time progresses the Mach front moves outward and increases in height. The distance from ground zero and the height of the Mach stem at the times indicated are shown in Table XVII to compare 20 KT and 1 MT bursts.

Table XVII

Height of Mach Stem

| Explosion Yield	Time After Detonation	Distance From Ground Zero	Height of Mach Stem
20 KT	3 sec	0.87 miles	185 feet
1 MT	11 sec	3.20 miles	680 feet
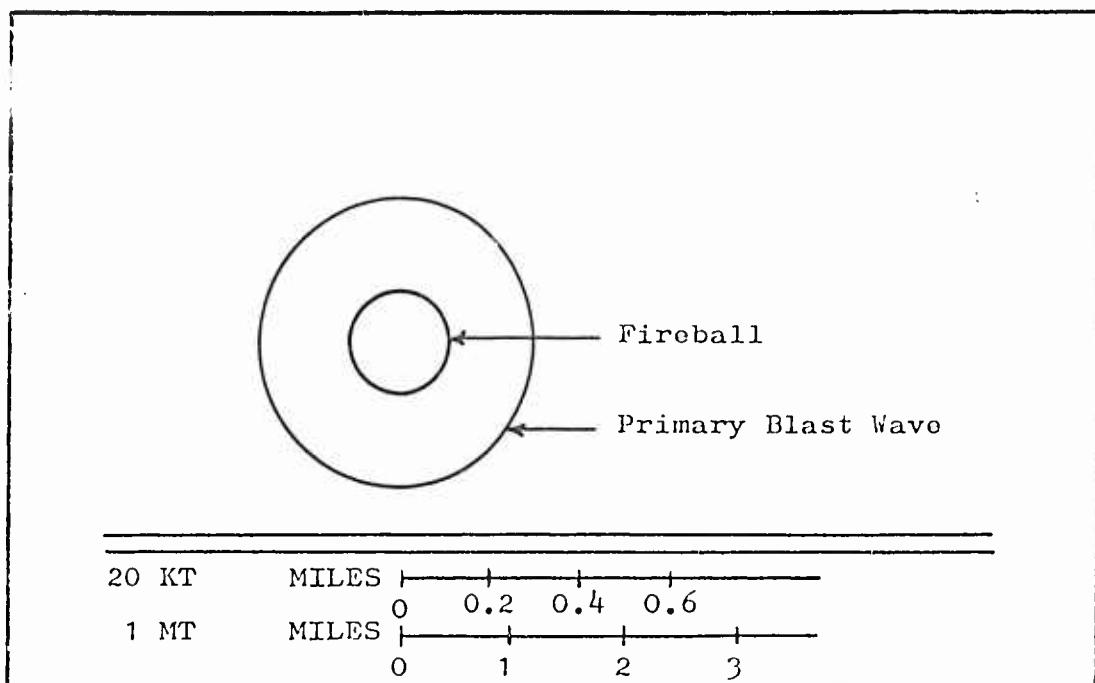
Figure 21. Air Burst at 0.5 second After 20 KT Detonation and 1.8 seconds After 1 MT Detonation
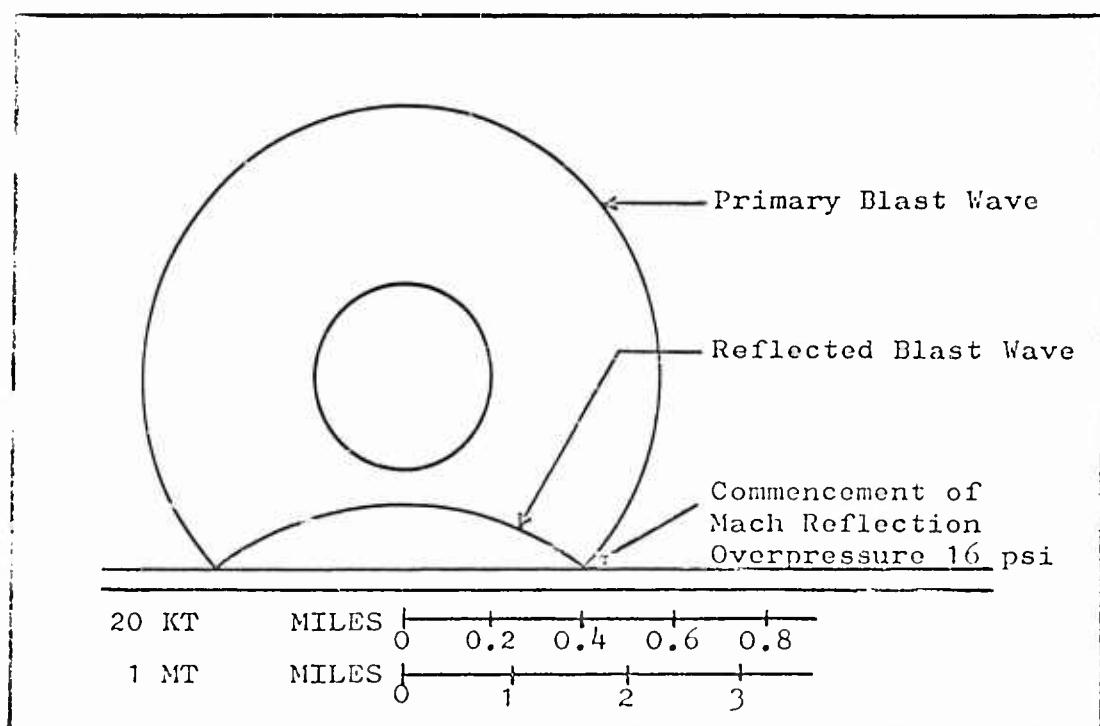

Figure 22. Air Burst at 1.25 seconds After 20 KT Detonation and 4.6 seconds After 1 MT Detonation

At the times indicated in Table XVII the overpressure at the Mach front is 6 psi and the blast wind velocity immediately behind the front is about 180 miles per hour. These conditions are illustrated in Figure 23.

At ten seconds after a 20 KT explosion the Mach front is over $2\frac{1}{2}$ miles from ground zero; and 37 seconds after a 1 MT detonation it is nearly $9\frac{1}{2}$ miles from ground zero. The overpressure at the front is roughly 1 psi in both cases, and the wind behind the front is 40 miles per hour. Apart from plaster damage and window breakage, the destructive effect of the blast wave is essentially over, and thermal radiation is no longer important, even for the 1 MT burst. These phenomena are shown in Figure 24.

The ball of fire is no longer luminous, but it is very hot and it behaves like a hot air baloon, rising at a rapid rate. As it ascends, it causes air to be drawn inward and upward, somewhat similar to the updraft of a chimney. This produces strong air currents, called afterwinds, which raise dirt and debris from the earth's surface to form the stem of what will eventually be the characteristic mushroom cloud.

The hot residue of the bomb continues to rise, and at the same time it expands and cools. As a result, the vaporized fission products and other bomb residues condense to form a cloud of highly radioactive particles. The afterwinds, having velocities of 200 mph or more, continue to raise a column of dirt and debris which will
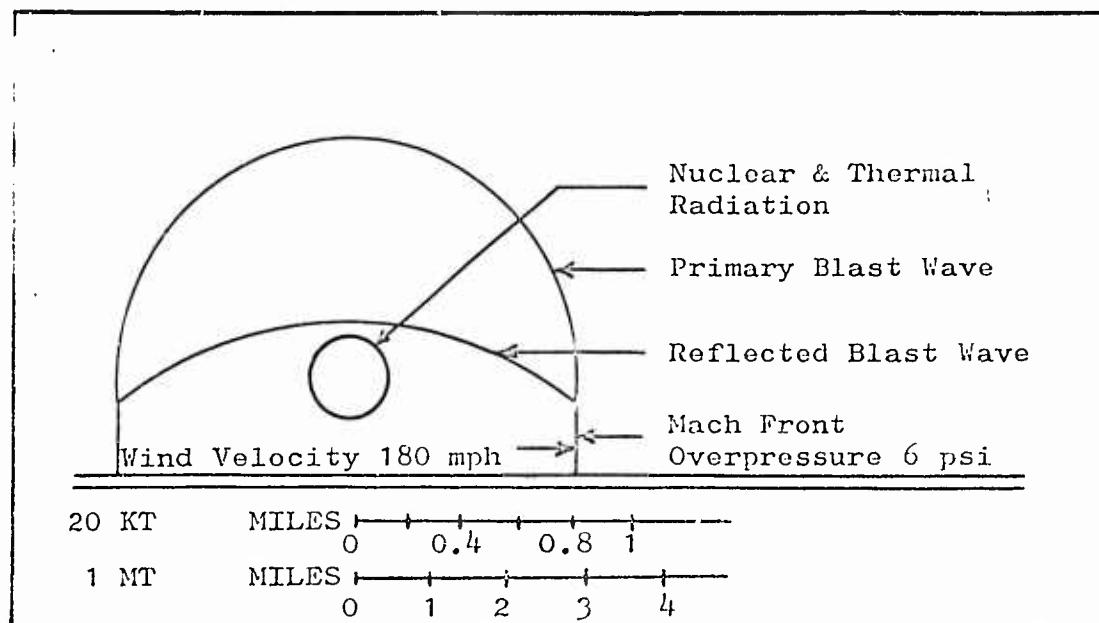
Figure 23. Air Burst at 3 seconds After 20 KT Detonation and 11 seconds After 1 MT Detonation
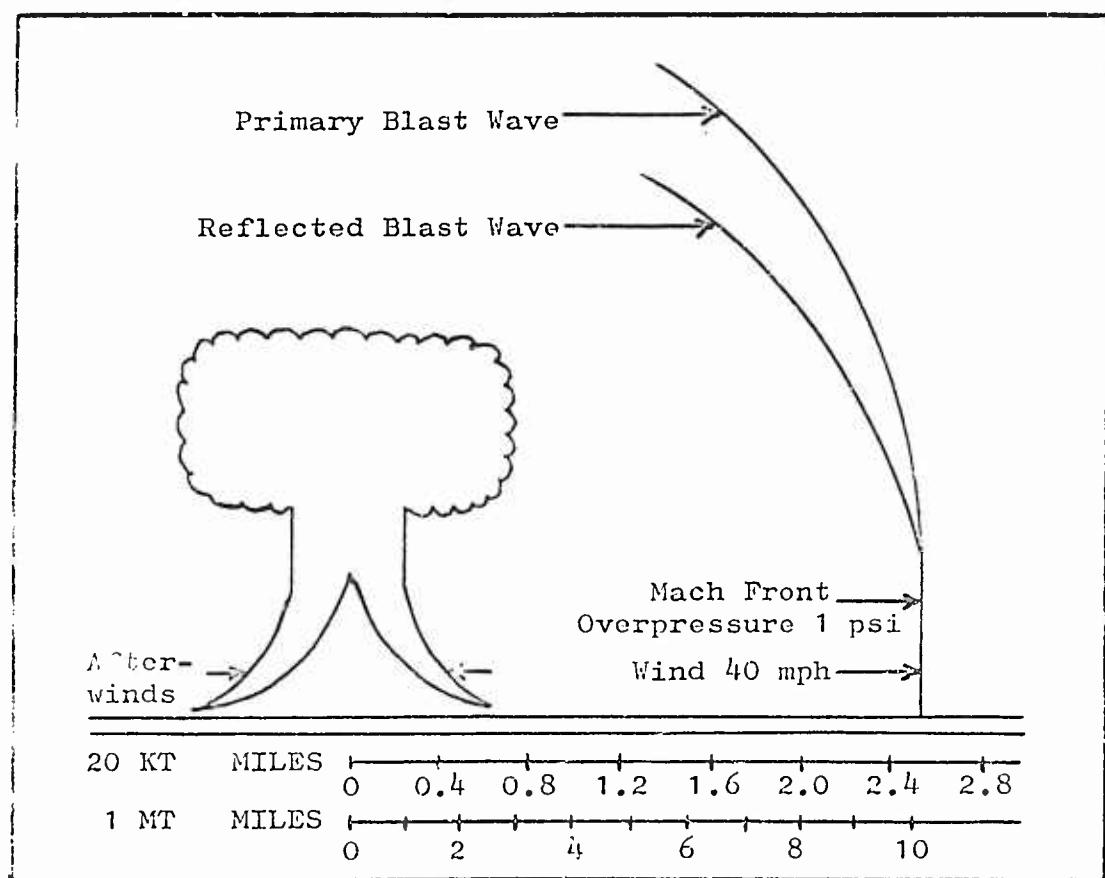

Figure 24. Air Burst at 10 seconds After 20 KT Detonation and 37 seconds After 1 MT Detonation
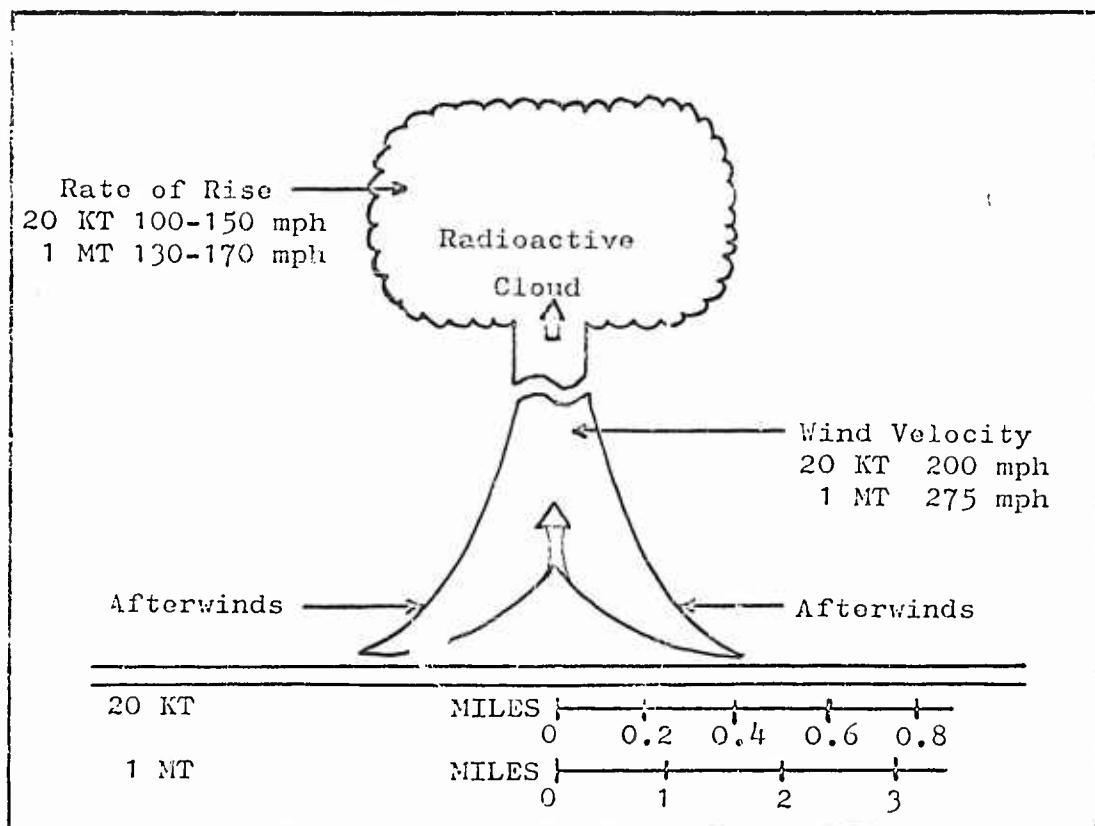
Figure 25. Air Burst at 30 seconds After 20 KT Detonation and 110 seconds After 1 MT Detonation

later join with the radioactive cloud to form the mushroom shape. At the times indicated in Figure 25, the cloud from a 20 KT explosion will have risen about $1\frac{1}{2}$ miles; and the cloud from a 1 MT explosion will have risen about 7 miles.

Within about ten minutes the bottom of the cloud will have attained an altitude of 5-15 miles. depending on the energy yield of the explosion. The top of the cloud will rise even farther. Ultimately, the particles will be dispersed by the wind, and, except under weather conditions involving precipitation, there will be no appreciable local fallout.

Air Blast Phenomena

Most of the material damage caused by an air burst nuclear bomb is due, directly or indirectly, to the shock wave which accompanies the explosion. The majority of structures will suffer some damage from air blast when the overpressure is about $\frac{1}{2}$ psi or more. This overpressure is created by the increase in air pressure caused by the air compression in the shock wave. The name is descriptive because it is the pressure of the air over that associated with normal atmospheric pressure. This overpressure acts much the same as the ordinary pressure of the air, i.e., in all directions, from all sides, from the top, and even through the soil to some extent. It produces a general inward-directed crushing effect on any structure above the ground.

The distance to which this overpressure level will extend depends on the yield or size of the bomb, and on the height of the burst. Consequently, it is desirable to consider the phenomena associated with the passage of a blast wave through the air.

As already seen, the expansion of the intensely hot gasses at extremely high pressures in the ball of fire causes a blast wave to form in the air, moving outward at high velocity. As the blast wave travels in the air from its source, the overpressure at the front steadily decreases, and the pressure behind the front falls off in a regular manner. After a short time, when the shock

front has traveled a certain distance from the fireball, the pressure behind the front drops below that of the surrounding atmosphere and a so-called "negative phase" of the blast wave forms.

During the negative overpressure phase, a partial vacuum is produced and the air is sucked in instead of being pushed away, as it is when the overpressure is positive. At the end of the negative phase, the pressure has essentially returned to ambient. The peak negative values of the overpressure are small compared with the peak positive overpressures.

Although the destructive effects of the blast wave have usually been related to the values of the peak overpressure, there is another quality of importance called the "dynamic pressure". The dynamic pressure is a function of the wind velocity and the density of the air behind the shock front. For very strong shocks the dynamic pressure is larger than the overpressure, but below 69 psi at sea level the dynamic pressure is smaller.

The dynamic pressure decreases with increasing distance from the explosion center at a more rapid rate than the overpressure. Since the dynamic pressure is lower than overpressure in the range below 69 psi, the effects of dynamic pressure on this study are insignificant. Specific levels of overpressures used in this paper are developed in Chapter IV, which will verify this conclusion.

As stated previously, there is a finite time interval
required for the blast wave to move out from the explosion
center to any particular location. This time interval is
an important parameter for the formulation of the model in
Chapter IV. This time interval is dependent upon the
energy yield of the explosion and the distance invloved.
Initially, the velocity of the shock front is quite high
--many times the speed of sound. As the blast wave prog-
resses outward, it slows down as the shock front weakens.
Finally, at long ranges, the blast wave becomes essentially
a sound wave, and its velocity approaches ambient sound
velocity.

Mach Effect

When the incident blast wave from an explosion in
the air strikes a more dense medium such as the earth's
surface, it is reflected. The formation of the reflected
shock wave under these circumstances is represented in
Figure 26. This figure shows four stages in the outward
motion of the spherical blast originating from an air
burst bomb.

In the first stage the shock front has not reached
the ground. The second stage is later in time, but still
has not reached the ground. At the third stage, which is
still later, a reflected wave has been produced and is
indicated by a dashed line in Figure 26. The fourth
stage is even later and indicates the growth of the
reflected wave.
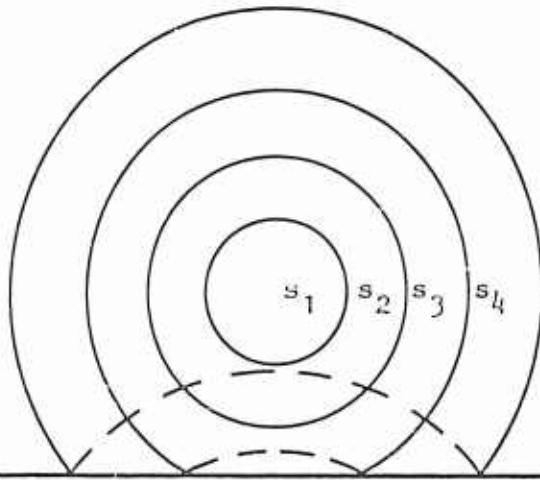
Note: s_1 thru s_4 Represent Succeeding Time Stages

Figure 26. Reflection of Blast Wave at Earth's Surface

When the reflection occurs, an individual or object precisely at the surface will experience a single shock, since the reflected wave is formed instantly. Consequently, the value of the overpressure experienced at the surface is considered to be entirely a reflected pressure. In a region near ground zero, this total reflected overpressure will be more than twice the value of the peak overpressure in the incident blast wave.

In the very early stages of the reflection period, the two shock waves are traveling at approximately the same speed. However, it is evident that the reflected wave always travels through air that has been heated and

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compressed by the passage of the incident wave. As a result, the reflected shock front moves faster than the incident shock front and, under certain conditions, eventually overtakes it so that the two shock fronts fuse to produce a single shock. This process of wave interaction is called "Mach" or "irregular" reflection. The region in which the waves have merged is therefore called the Mach region, in contrast to the regular region where they have not merged.

The fusion of the incident and reflected shock fronts is indicated schematically in Figure 27, which shows a portion of the profile of the blast wave close to the surface.


R = Reflected Wave
I = Incident Wave
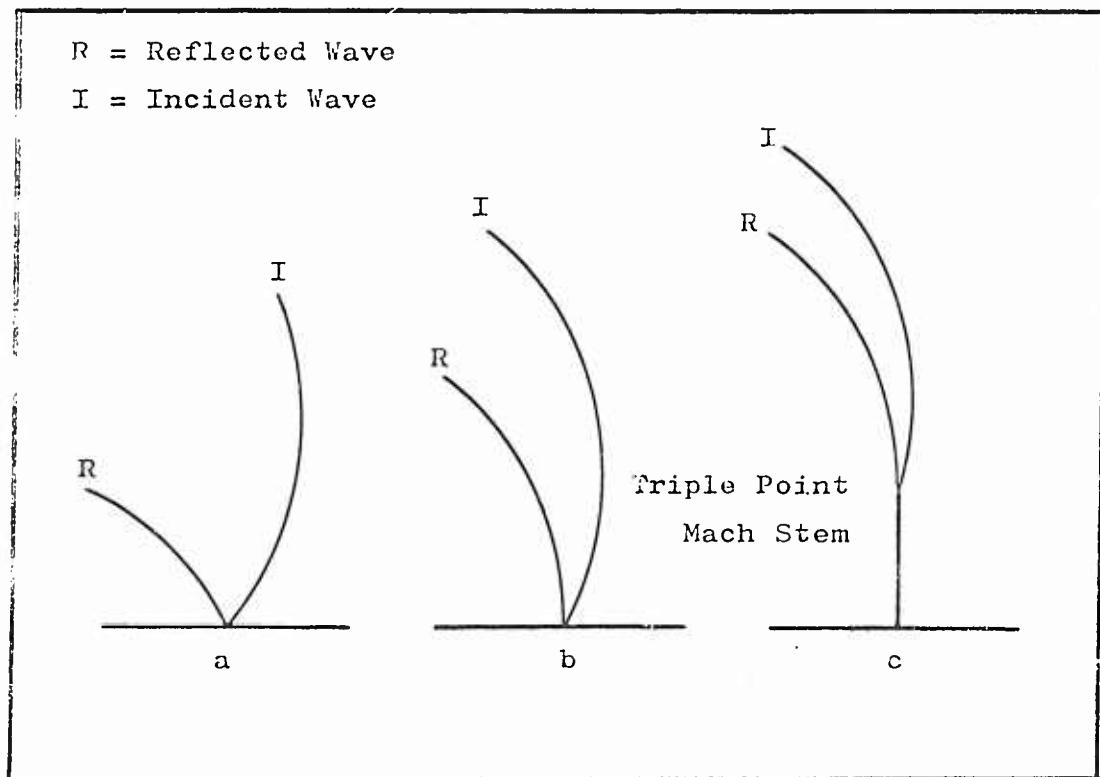
Figure 27. Formation of the Mach Stem

Figure 27a represents the situation at a point fairly close to ground zero. At a later stage, farther from ground zero as in Figure 27b, the steeper front of the reflected wave shows that it is traveling faster than, and is catching up with, the incident wave. At the stage represented in Figure 27c, the reflected shock near the ground has overtaken and fused with the incident shock to form a single shock front called the Mach stem. The point at which the incident shock, reflected shock, and Mach fronts meet is called the "triple point".

As the reflected wave continues to overtake the incident wave, the triple point rises and the height of the Mach stem increases as in Figure 28.
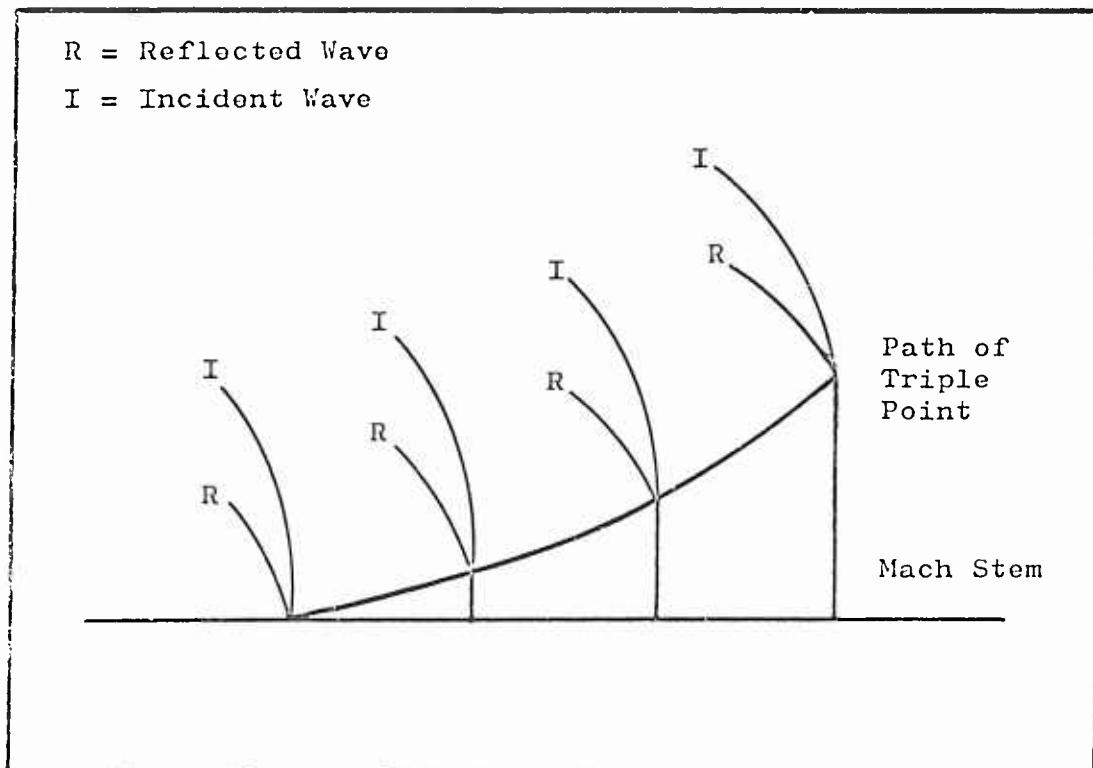

Figure 28. Growth of the Mach Stem

Any object located at or above the ground, within the Mach region, and below the triple point path, will experience a single shock. At points in the area above the triple point path, such as an aircraft or the top of a tall building, two shocks will be felt. Near the triple point path these two shocks can occur within a very short time of each other, and this could be critical from a structural point of view.

Height of Burst

The height of burst and energy yield of a nuclear explosion are important factors in determining the extent of damage at the surface. These two quantities generally determine the variation of pressure with distance from ground zero and other associated blast wave characteristics, such as the distance from ground zero at which the Mach stem begins to form. As the height of burst for an explosion of given yield is decreased, the consequences are as follows: the Mach reflection commences nearer to ground zero; and the overpressure at the surface near ground zero becomes larger. An actual contact surface burst leads to the highest possible overpressures near ground zero.

Because of the relationships between the energy yield of the explosion and the height of burst required to produce certain blast effects, a very large yield weapon may be detonated at a height of several thousand feet above the ground. The accompanying blast wave

phenomona will approach thoso of a near surface burst.

Actually there is no single optimum height of burst, with regards to blast effects, for any specified explosion yield, because the chosen height will be determined by the nature of the target. As a rule, strong (or hard) targets will require low air or surface bursts. For weaker targets which are destroyed or damaged at relatively low over-pressures or dynamic pressures, the height of burst may be raised in order to increase the area of damage, since these pressures will extend to a larger range than for low air or surface bursts.

Effects of Target Altitude

The relationships between overpressure, distance, and time that describe the propagation of a blast wave in the air depend upon the ambient atmospheric conditions, which vary with altitude.

There are a number of simple correction factors, but it will be sufficient for the present to state the general conclusions. With increasing altitude of both target and burst point, the overpressure at a given dis-tance from an explosion of specified yield will generally decrease. Consequently, an increase may usually be ex-pected in both the arrival time of the shock front and in the duration of the positive phase of the blast wave. For elevations less than 5000 feet above sea level, the changes are small and may be disregarded in calculations involving overpressure, distance, and time.

Scaling Laws

The basic relationships among the properties of a blast wave are derived from the Rankine-Hugoniot conditions based on the conservation of mass, energy, and momentum at the shock front. These conditions, together with the equation of state for air, permit the derivation of the required relations involving the shock velocity, over-pressure, and other phenomena.

In order to calculate the characteristic properties of the blast wave from an explosion of any given energy if those for another energy are known, appropriate scaling laws are applied. With the aid of such laws it is possible to express the data for a large range of energies in a simple form. One way of doing this, which will be illustrated below, is to draw curves showing the change in various properties of the blast wave at the surface with increasing distance from the detonation of a 1 KT explosion. Then, with the aid of the scaling laws, the values for the explosion of any specified energy can be determined for a particular height of burst.

Theoretically, a given pressure will occur at a distance from an explosion that is proportional to the cube root of the energy yield. According to this law, if d_1 is the distance from a reference explosion of W_1 KT at which a certain overpressure or dynamic pressure is attained, then for any explosion of W KT energy, these same pressures will occur at a distance (d) given by:

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$$\frac{d}{d_1} = \left(\frac{W}{W_1}\right)^{1/3}$$

The reference explosion is conveniently chosen to be 1 KT so that W_1 is equal to one. It follows from the equation above that where d_1 is the distance from a 1 KT explosion, the formula reduces to:

$$d = d_1 W^{1/3}$$

Consequently, if the distance (d) is specified, then the value of the explosion energy (W) required to produce a certain effect can be calculated.

When comparing air bursts having different energy yields, it is convenient to introduce a scaled height of burst, defined as:

$$\text{Scaled Height of Burst} = \frac{\text{Actual Height of Burst}}{W^{1/3}}$$

Cube root scaling can also be applied to arrival time of the shock front. The relationship may be expressed in the form:

$$\frac{s}{s_1} = \frac{d}{d_1} = \left(\frac{W}{W_1}\right)^{1/3}$$

Where s_1 represents arrival time for a reference explosion of energy W_1, and s refers to the arrival time for any explosion of energy W. As before, d_1 and d are distances from ground zero. If W_1 is 1 KT, then these quantities are related as follows:

$$s = s_1 W^{1/3}$$

at a distance $d = d_1 W^{1/3}$

Altitude Corrections

The data presented above for the characteristic properties of a blast wave are strictly applicable to a homogeneous atmosphere at sea level. However, this condition holds for bursts up to about 5000 feet altitude. If it is required to determine the air blast parameters at altitudes where the ambient atmospheric conditions are appreciably different from those at sea level, then a correction factor must be applied.

The general relationships which take into account the fact that the absolute temperature (T) and the ambient pressure (P) are not the same as T_o and P_o respectively, in the reference (1 KT) explosion in a sea level atmosphere, are as follows:

For the overpressure, $p = p_1 \dfrac{P}{P_o}$,

where p is the overpressure at altitude and p_1 is that at sea level.

For the arrival time, $s = s_1 W^{1/3} \left(\dfrac{P_o}{P}\right)^{1/3} \left(\dfrac{T_o}{T}\right)^{1/2}$

where s is the arrival time at altitude and s_1 is that at sea level.

The foregoing expressions are applicable when the altitude at the observed point (or target) does not

differ by more than a few thousand feet from that at the point of burst.

As a general rule, the referenced values for the blast wave properties are for a standard sea level atmosphere, where P_0 is 14.7 psi and the temperature is 59 degrees Fahrenheit (15 degrees Centigrade), so that T_0 is 519 degrees Rankine (288 degrees Kelvin).

Standard Curves

In order to estimate the damage which might be expected to occur at a particular range from a given explosion, it is necessary to define the characteristics of the blast wave as they vary with time and distance. Standard height of burst curves of the various air blast wave properties are given here to supplement the general discussion already presented.

From the curves given below, the values of the blast wave properties at the surface can be calculated and the results used to determine the loading and response of a particular target.

These standard curves show the blast wave properties for a 1 KT explosion. To simplify calculations, Figure 29 gives the values of cube roots required in the application of scaling laws.

The variations of peak overpressure with distance from ground zero for a 1 KT TNT equivalent contact surface burst in a standard sea level atmosphere are represented by the curves in Figure 30.

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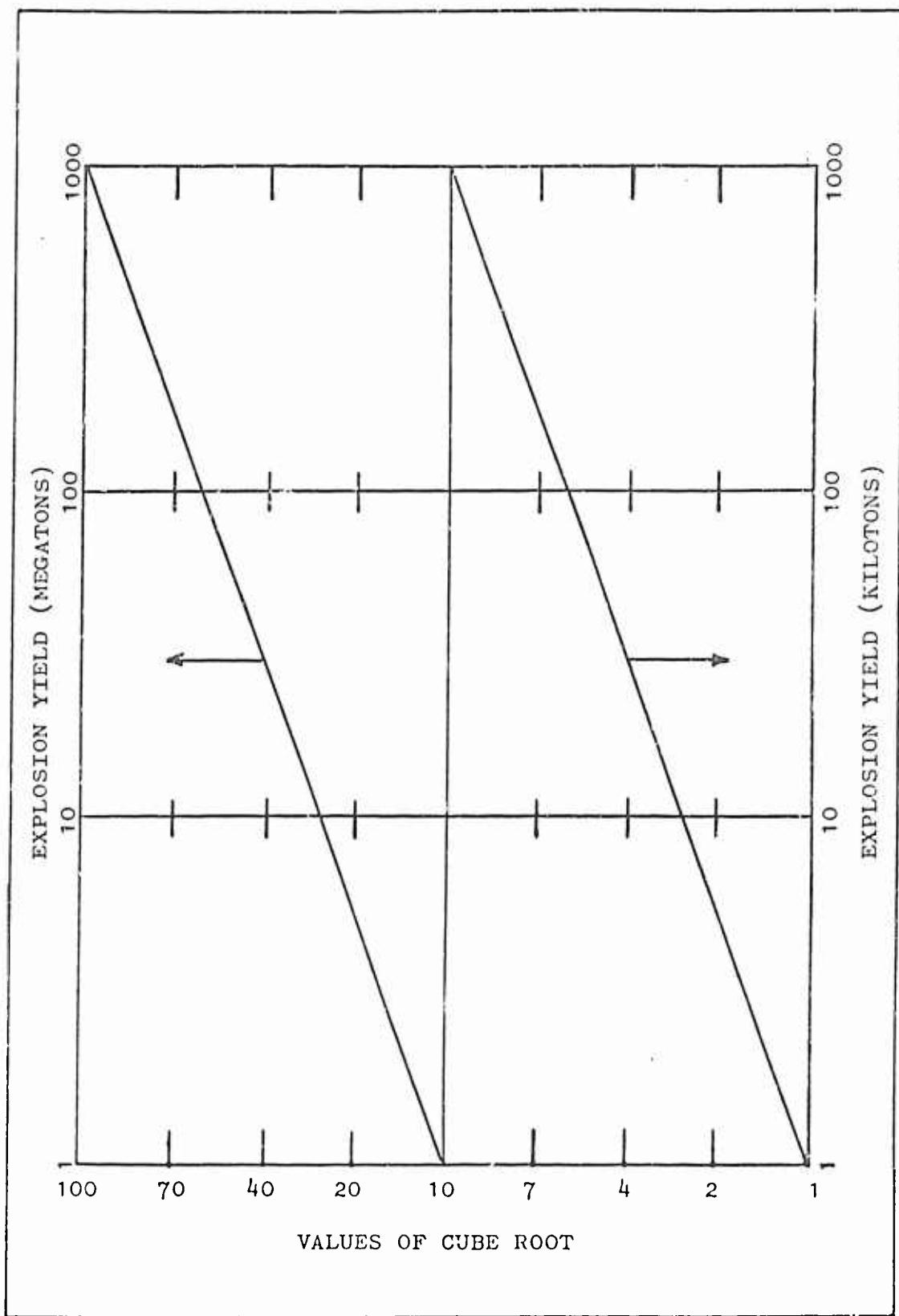
Figure 29. Cube Root Scaling Factor
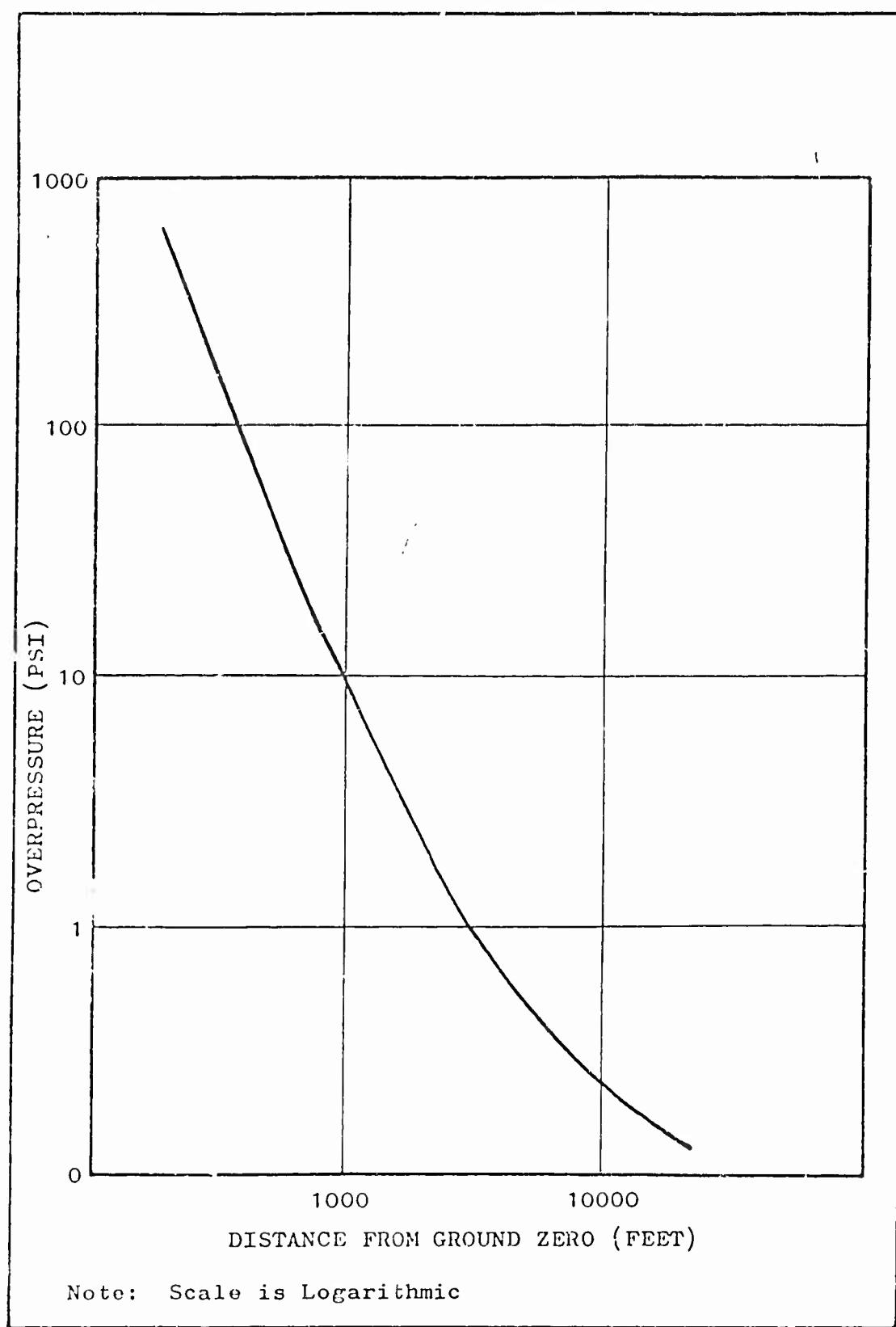
Figure 30. Peak Overpressure for 1 KT Surface Burst

The curve in Figure 31 shows the variation of peak overpressure for a 1 KT air burst, with distance from ground zero as a function of the height of burst. The presence of a pronounced "knee" in the curves in the Mach region means that, for any given overpressure, there is an optimum burst height that maximizes the distance from ground zero at which this overpressure is experienced. The corresponding data for any other explosion energy yield may be obtained by use of the scaling laws. The peak overpressures in Figure 31 are those that would be observed at or near the surface after reflection has taken place.

The curves in Figure 32 give the arrival times of the shock front on the ground at various distances from ground zero as a function of the height of burst for a 1 KT explosion under the conditions of a sea level atmosphere and a nearly ideal surface.

The curve in Figure 33 shows the height of the Mach stem for a 1 KT air burst. For yields other than 1 KT, the height and distance of the Mach stem scale as the cube root of the yield:

$$h = h_o W^{1/3}$$
$$d = d_o W^{1/3}$$

where h_o is the height of the Mach stem at distance d_o for 1 KT, and h is the height of the Mach stem at distance d for W KT.

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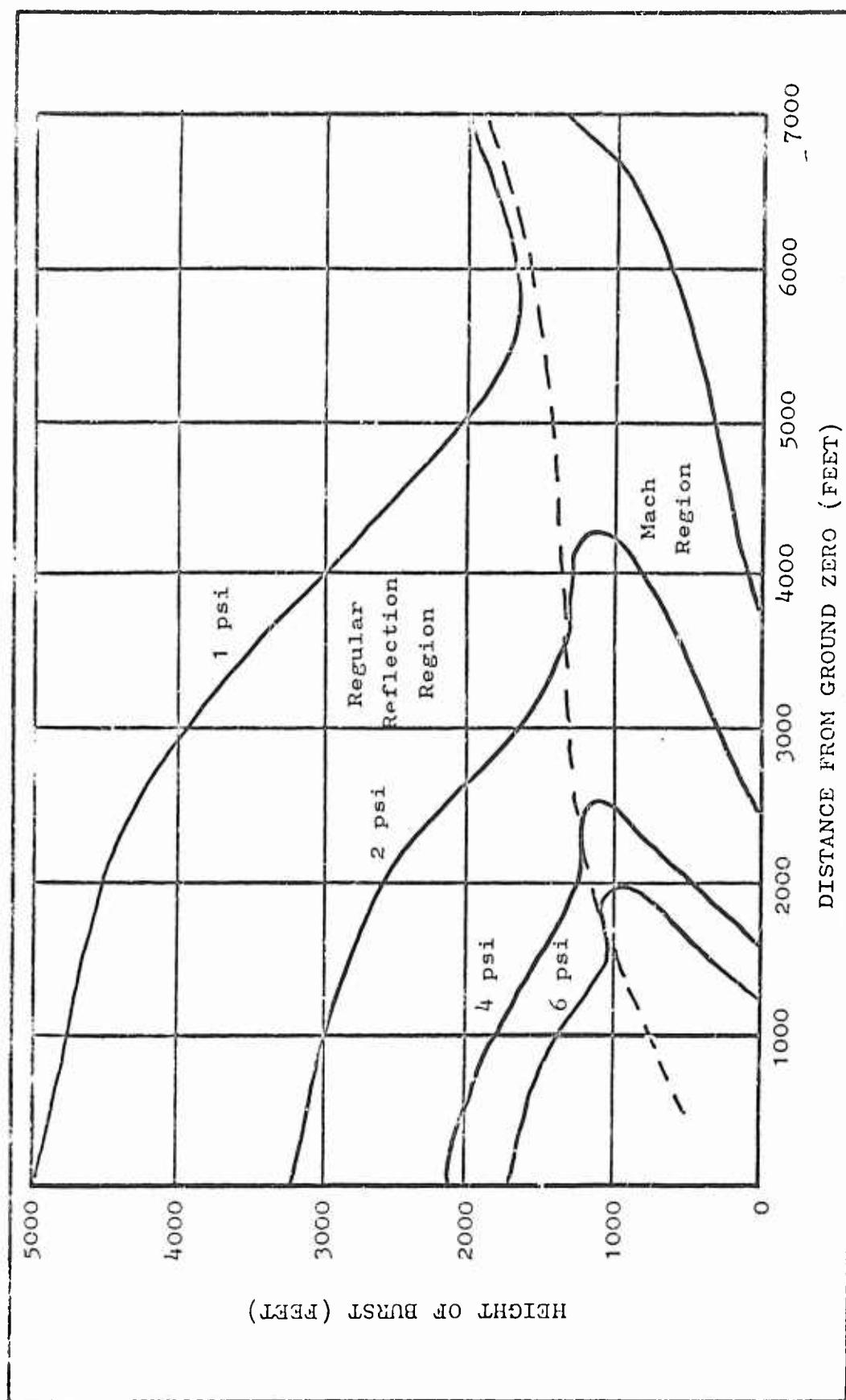
Figure 31. Peak Overpressure on the Ground for a 1 KT Burst
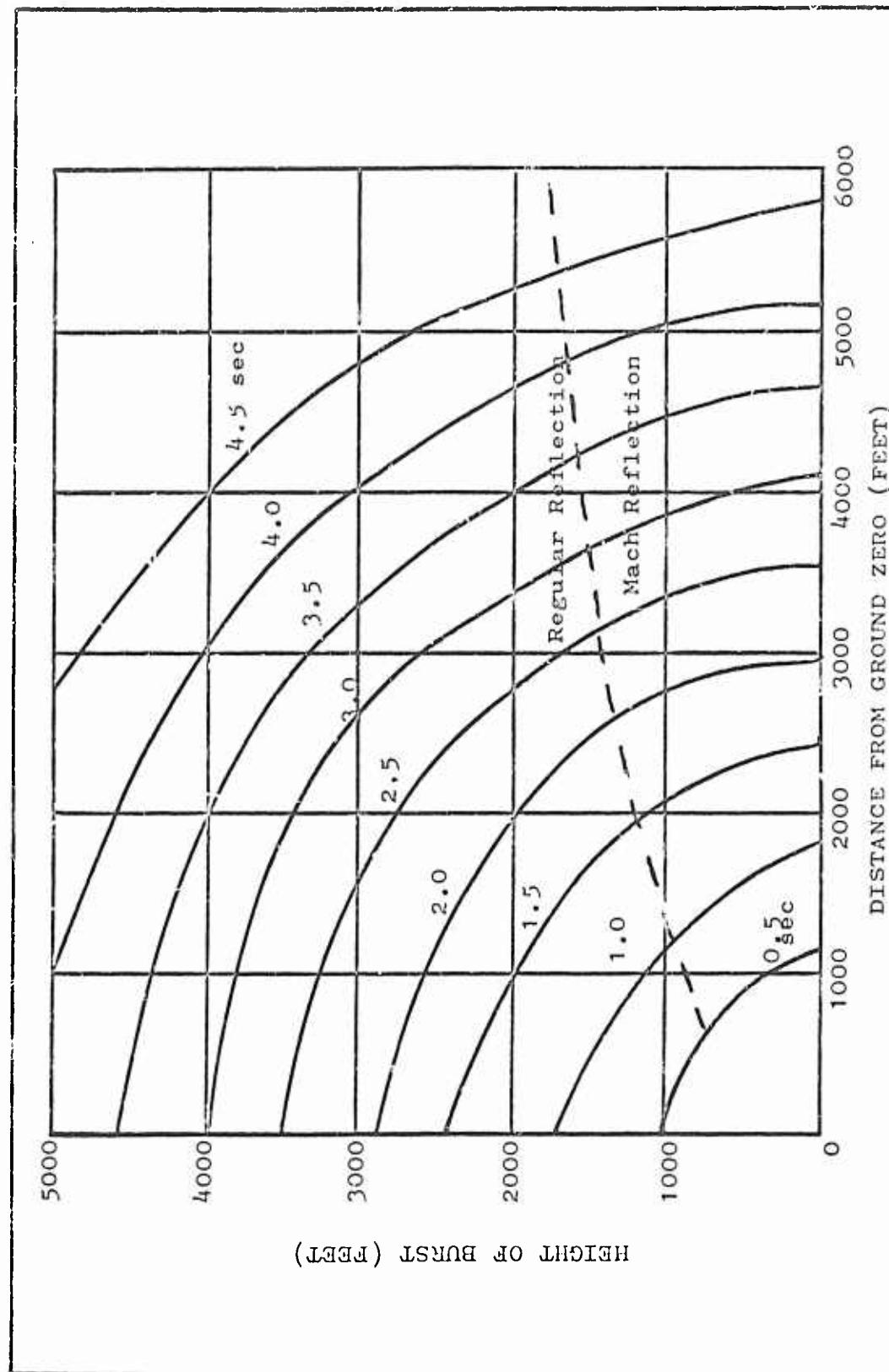
Figure 32. Arrival Times on the Ground of Blast Wave for 1 KT Burst
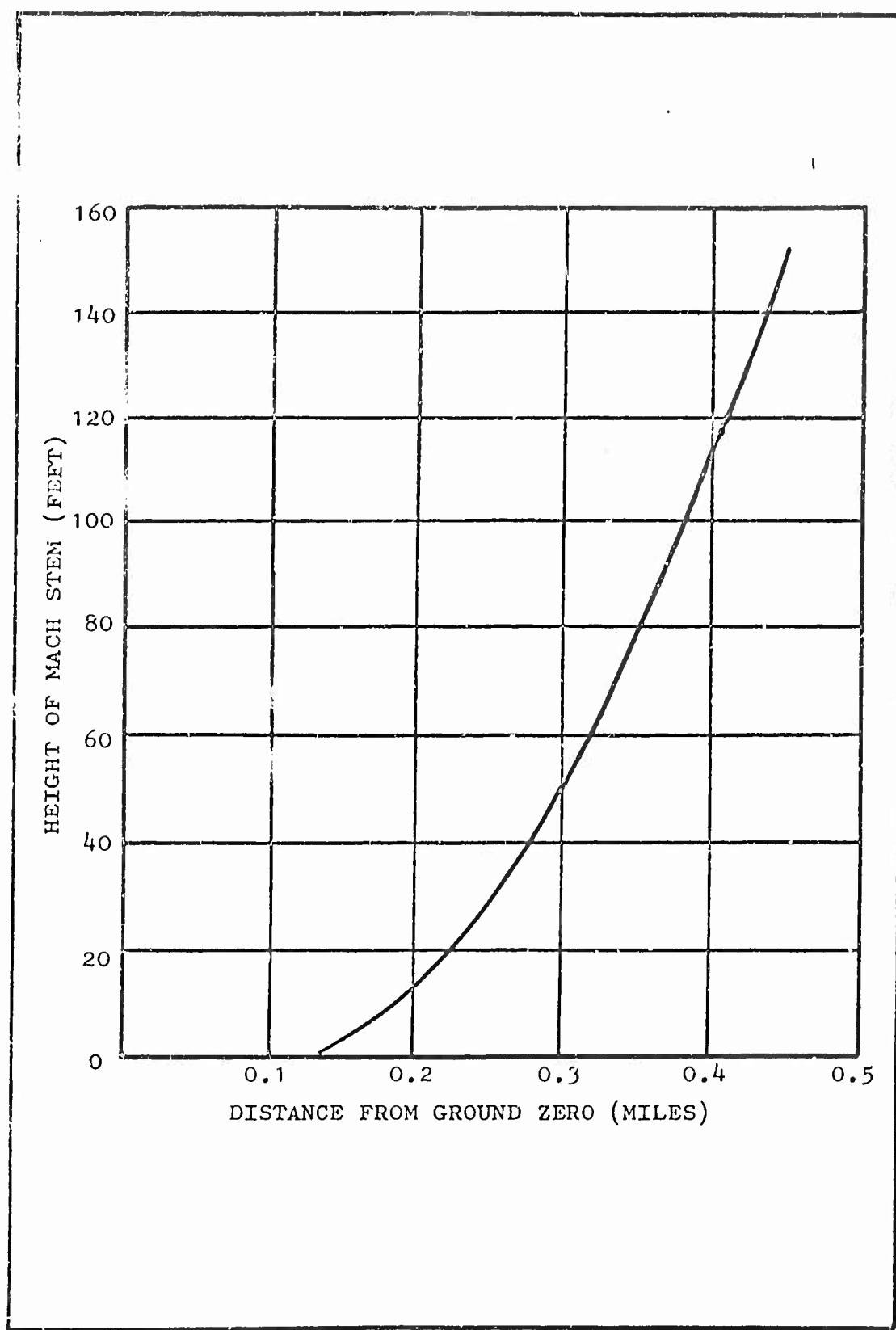
Figure 33. Height of Mach Stem (Path of Triple Point) for a 1 KT Air Burst

Appendix B

Summary of Airfield Data

Runway Length (feet)	NUMBER OF FIELDS BY CATEGORY			
	Air Force	Other Military	Civilian	Total
6000 - 7900	11	14	325	350
8000 - 9900	35	30	112	177
10000 - 11900	34	10	34	78
12000+	32	10	12	54
Total	112	64	483	659

Information presented in this summary was extracted from the IFR and VFR Supplements to the DOD Flight Information Publication (FLIP) (Ref 34 & 69).

Appendix C

Effect of SLBM Launch Interval

The analysis in Chapter V indicated that as long as there were fewer missile launching submarines than bases to be targeted, the interval between missiles launched from a single submarine would be a significant figure affecting the prelaunch survival of manned bombers.

Although it was not deemed feasible to consider missile launch interval in the deterministic, worst case formulation presented in this study, future exploration of a stochastic approach to the problem might well consider this interval of time.

The addition of one term to the survival equation will allow computation of the number of bombers surviving on a base in a particular zone, given the interval length and launch sequence number of the SLBM attacking that base. The modified equation would be:

$$a_{ij} = \frac{60}{I}(M - T) + \frac{S + L_p}{I} + 1$$

where L_p; $p = 0, 1, 2, \ldots, q$; is the cumulative length of the launch intervals until the SLBM attacking the base in question is launched; p is the number of intervals until that launch; and q is one less than the number of missiles on the submarine (e.g., considering current capabilities, $q = 16 - 1 = 15$).

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Whether the base in question is targeted on the first, second, or succeeding salvos would be dependent on the enemy's targeting strategy. If enemy targeting is uniform over all zones considered, then there is some probability associated with being targeted by any particular salvo; and it is the same probability in each location. If enemy strategy is based on some other criteria, such as target value or target distance, then the probability of being targeted on any given salvo would vary with these parameters.

In either case, these probabilities could be used in a stochastic formulation of a total force survival model.

VITA

Douglas D. Cochard was born on ████████ ██

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Southwest Texas State College. He graduated from pilot

training in August, 1962, and then attended combat crew

training in the F-100. His first operational assignment

was the 353rd Tactical Fighter Squadron at Myrtle Beach

AFB, S.C., where he spent $2\frac{1}{2}$ years as a fighter pilot and

bomb commander. While there he attended Squadron Officers

School at Maxwell AFB, Alabama, and the Army Airborne

Parachutist School at Ft. Benning, Georgia. He was as-

signed as an advisor to the Vietnamese 514th Fighter

Squadron at Bien Hoa in November, 1965, where he spent one

year flying 370 sorties and 634 combat hours in the A-1H.

A consecutive overseas tour to RAF Lakenheath, England,

returned him to the F-100 for $3\frac{1}{2}$ years where he was an

emergency actions officer with the 48th Tactical Fighter

Wing and an instructor pilot, test pilot, bomb commander,

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